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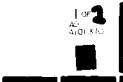

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Contents:

INTRODUCTION

This booklet contains brief summaries of the research programs supported by the Electronic and Solid State Sciences Program (Code 427) of the Office of Naval Research for the fiscal year 1979. Further information about these programs can be obtained either from the program director, Dr. J. O. Dimmock, at (202) 696-4216, or from the scientific officers:

Dr. J. M. Morris	(202) 696-4217
Dr. H. W. Mullaney	(202) 696-4214
Dr. L. R. Cooper	(202) 696-4214
Dr. G. B. Wright	(202) 696-4215
Mr. M. N. Yoder	(202) 696-4218
Mr. E. A. Edelsack	(202) 696-4218

SOLID STATE PHYSICS

NR 318-002, University of Pennsylvania, "Fundamental Studies and Random Systems", P. I. - Herbert Callen, A. Brooks Harris, and Tom C. Lubensky, (215) 243-8149, N00014-76-C-0106

A central theme is the application to non-thermodynamic transitions of the physical ideas and mathematical techniques developed for thermodynamic phase transitions. The percolation problem was the initial focus of this theme but, among other problems, the gelation of branched polymers has been studied recently, and currently the general approach is being extended for the study of electron localization in a random potential. The problem has been formulated as a field theory, and preliminary work has been carried out on a "random bond" model in which the transfer matrix element between sites can take the values $\pm t_0$ with equal probability. This model leads to a singularity well within the band edges, with a mean-field-theory critical exponent γ that is $\frac{1}{2}$ (rather than unity). Other types of randomness, non-perturbative "instanton" solutions for localized states, and the effects of electron-electron interactions are being studied. The localization problem exploits previous work on the statistics of "lattice animals", or isolated clusters of bonds on a lattice. That work too is being extended with the formulation of a field theory which constructs a generalized generating function for the lattice animals. The study of the lattice animals arose in the anlysis of gelation of branched polymers. T. Tanaka (Phys. Rev. Lett. 40, 820, 1978) has reported phase diagrams exhibiting phase separation of solvent and polymeric solute. The system can be modeled by a combined lattice-gas-Potts model, and this model is being studied by means of an ϵ-expansion. Parallel work is in progress on the reduction of effective dimensionality accompanying the spin ordering in Eu Se, where the equality of magnitudes of the first and second neighbor interactions effectively decouples neighboring planes of spins. Another problem under investigation is the phase transition at zero temperature in the Ising model with a transverse field. This model is being studied by a series expansion in the ratio of exchange constant to magnetic field, using existing analysis of the cluster diagrams generated by the expansion. Progress: In the past year significant advances have been made in the theory of the statistics of lattice clusters and the gelation of branched polymers, largely through the invention of a classical field theory which generates a partition function identical to the generating function of lattice clusters. In particular it was shown that gelation and vulcanization are equivalent to percolation near threshold; that for the dilute limit of branched polymers in a good solvent the critical dimensionality d_c is 8, and in other solvent conditions it is 6; that below d_c the hyperscaling relation $d\nu=2=\alpha$ is strongly violated; and that the values of critical exponents depend on the boundary conditions imposed on the fugacities or the fields, thereby rationalizing specific results found by other investigators. Another accomplishment of the past year was the development of a Langevin theory for the dynamics of nematic and smectic liquid crystals, permitting a calculation of the critical enhancement of viscosities to first order in mode-mode coupling. The nuclear magnetic resonance measurements of low-density pairs of ortho-hydrogen molecules in solid para-hydrogen, carried out by Professor Horst Meyer and his group at Duke University, have been analyzed, thereby evaluating the interaction of ortho-molecules. The orientational state of two-dimensional solid ortho-hydrogen films have been obtained via a mean-field analysis, providing a phase diagram of fairly rich structure. A tricritical point is predicted, and a "ferro-phase" having the same symmetry as the two dimensional x-y model, and two phases with two sublattices and one phase with four sublattices are all found. Finally the energies of domain

walls in (111)-oriented magnetic films has been calculated, with relevance to the propagation of bubbles in films with ion-implanted propagation structures. These calculations provide an explanation of the propagation characteristics observed by Lin, Dave, Schwarzl and Shir at IBM.

Recent Publications:

1. Anisotropic Critical Properties of the de Gennes Model for the Nematic to Smectic-A Transition, T. C. Lubensky and Jing-Huei Chen, Phys. Rev. B17, 366 (1978).

2. Renormalization Group Treatment of the Random Resistor Network in 6-ε Dimensions, C. Dasgupta, A. B. Harris and T. C. Lubensky, Phys. Rev. B17, 375 (1978).

3. Crossover Near Fluctuation-Induced First Order Transitions in Superconductors, Jing-Huei Chen, T. C. Lubensky and David R. Nelson, Phys. Rev. B17, 4274 (1978).

4. Critical Exponents for the Zero State Potts Model in 2 + ε Dimensions, T. C. Lubensky, Phys. Lett. 67A, 169 (1978).

5. Field Theory for the Statistics of Branched Polymers, Gelation and Vulcanization, Phys. Rev. Lett. 41, 829 (1978).

6. Statistics of Trees and Branched Polymers from a Generalized Hilhorst Model, T. C. Lubenksy, Chandan Dasgupta and C. M. Chaves, J. Phys. A11, 2219 (1978).

7. Textural Singularities and Frustration in Random-Anisortropy and Random-Field Models, S. Alexander and T. C. Lubensky, Phys. Rev. Lett. 42, 125 (1979).

8. Magnetic Transitions in Europium Selenide, H. Callen and M. A. DeMoura, Jour. Magn. Mat. 2, 581 (1978).

9. The Effect of Elastic Properties of SiO_2 Spacer on Bubble Pinning, B. Stein, H. Callen, M. Casey, R. Josephs, Journ. Appl. Phys. 49, 3 (1978).

10. Critical Behavior of Random Resistor Networks Near the Percolation Threshold, R. Fisch and A. B. Harris, Phys. Rev. B18, 416 (1978).

11. Orientational Phase of Hydrogen Molecules on a Triangular Lattice, A. Berlinsky, and A. B. Harris, Phys. Rev. Lett. 40, 1579 (1978).

12. Dynamics Near the Nematic-Smectic-A and Nematic-Smectic-B Phase Transition in Liquid Crystals, K. A. Hossain, J. Swift, J. H. Chen, and T. C. Lubensky, Phys. Rev. B19, 432 (1979).

NR 318-005, University of Pennsylvania, "Optical and Acoustical Spectroscopy of Solids," P. I. - Elias Burstein, (215) 243-8160, N00014-76-C-0107

Our long range goal is to investigate, experimentally and theoretically, electromagnetic and elastic wave pheonomena and to use these pheonomena as spectroscopic probes of electronic and vibrational excitations at surfaces and interfaces.

Currently we are focussing our attention on the electromagnetic properties of metals, and of molecules adsorbed at metal surfaces, including the effects of sub-microscopic roughness. We are, in particular, investigation second harmonic generation at metal surfaces, and luninescence of adsorbed molecules on metals. During the coming year we hope to make some progress in elucidating the role played by electron-hole pairs in the metal in the excitation and emission of luminescence by the adsorbed molecules. We plan also to explore the possibility of using luminescence as a spectroscopic probe of the electronic structure of the adsorbed molecule-metal "complex". Progress: (1) In order to obtain further clarification of the role played by surface roughness in the greatly enhanced Raman scattering by molecules adsorbed on Ag electrodes, and in the greatly enhanced inelastic light scattering by Ag electrodes without adsorbed molecules, we have measured the second harmonic generation (SHG) from a smooth ($\sim 2000\mathring{A}$) Ag film and from a thin ($\sim 50\mathring{A}$) Ag island (e.g., aggregated) film using 1.06 micron Na-YAG laser radiation. The SHG signal from the Ag island film was an order of magnitude greater than that from the smooth film. We also found that the SHG signal from an Ag island film with an absorved layer of isonicotinic acid (a configuration which exhibits a strongly enhanced Raman scattering) was not appreciably different from that for an Ag island film without the adsorbed molecules. (2) Measurements of the infrared absorption by a monolayer of CN^- adsorbed from aqueous solution onto the (110) surface of a single crystal of Ag using surface electromagnetic waves in an ATR prism configuration, indicate that there is no sizeable metal-mediated enhancement of the oscillator strength of the CN stretch vibration mode. (3) In preliminary experiments on the luminescence of dyes adsorbed on Ag, such as fluorescein isothiocyanate, rhodamine 6-G and cresyl violet acetate, we find that, when the dyes are adsorbed on a smooth Ag film, their luminescence is "completely" quenched. On the other hand, when the dyes are adsorbed on thin ($\sim 50\mathring{A}$) Ag island films, we observe a luminescence which is an order of magnitude greater than that of the dyes adsorbed on a glass substrate. Furthermore, the luminescence is accompanied by an enhanced Raman scattering by the adsorbed molecules, which is comparable in strength to that of the luminescence. We plan next to explore the possibility of observing metal-sensitized luminescence by molecules, such as the Eu^{3+} complexes, whose optical excitation is "forbidden."

Recent Publications:

1. "Giant Raman Scattering and Luminescence by Molecules Adsorbed on Ag and Au Metal Island Films", C. Y. Chen, I. Davoli, C. Ritchie, and E. Burstein. Proc. Intl. Conf. on Non-traditional Approaches to the Study of the Solid-Electrolyte Interface, Surface Science (in press)

NR 318-007, University of California, Santa Barbara, "High Injection Level Recombination Radiation in Indirect Semiconductors", P. I. - Herbert Kroemer, (805) 961-3078, N00014-76-C-1044

This contract is in a transition from one objective to another. For some time, high-field effects in an organic semiconductor, TTF-iodide, were being studied to determine whether this unique quasi-one dimensional material had any potential

for electronic applications. The new objective concerns a study of various effects of very high levels of population inversion in indirect-gap semiconductors. In such materials, population inversions should be achievable that are far above those at which conventional laser action would take place in a direct-gap semiconductor. Numerous new physical effects are expected at such high levels, both in the band structure, in the light emission properties, and in the transport properties. The change in objectives was undertaken for two different but mutually supporting reasons. (a) The work on TTF-iodide had always suffered from the lack of a first-rate organic chemistry backup capability, nor did the results justify the acquisition of such a capability. (b) The P. I. was about to acquire MBE equipment, which offered far greater opportunities to make a significant contribution to solid state science. Progress: The TTF-iodide work was furnished during this reporting period; it is currently being written up. On the high-level injection objective, we have assembled and tested infrared instrumentation consisting of a McPherson 2051 Spectrometer with 2 detectors, a phase-lock amplifier and a separate boxcar averager, the latter purchased under this contract. With the instrumentation phase complete, the work has shifted towards MBE growth of Ge-on-GaAs p-n single heterostructures, to be followed by GaAs-on-Ge-on-GaAs p-p-n double heterostructures.

Recent Publications:

(none)

NR 318-009, Rensselaer Polytechnic Institute, "Wave-Solid Interactions", P. I. - Harry F. Tiersten, (518) 270-6544, N00014-76-C-0368

Theoretical studies of the interaction of the electromagnetic field with heat conducting and electrically non-conducting and conducting polarizable and magnetizable deformable solid continua are being undertaken in order to obtain consistent macroscopic descriptions of the interactions. In addition, problems concerning the vibrations of piezoelectric plates and rods and the propagation of piezoelectric plates and rods and the propagation of piezoelectric surface waves are being treated in order to increase the understanding and predictability of the behavior of these classes of devices. The temperature dependence of the resonant frequencies of electroded quartz resonators vibrating in trapped energy modes is being calculated by means of a perturbation procedure along with an approximate analysis of the thermal stresses in the electroded quartz plate. An analysis of driven thickness-extensional trapped energy vibrations in PZT-7A plates is being performed using an unconstrained variational principle. The small amount of energy lost by the trapped mode, which has been ignored in other treatments, is included in this treatment. A macroscopic boundary condition at the surface of a semiconductor, which is required for consistency with the usual inhomogeneous semiconduction force equation, is being applied in the interpretation of C-V measurements. When the material surface coefficients occurring in the description have been obtained from some measurements, the theory will be applied in the prediction of other measurements. Progress: The temperature dependence of the resonant frequencies of electroded doubly-rotated quartz thickness-mode and contoured AT-cut quartz resonators have been calculated. The nonlinear differential equations describing the extensional motion of anisotropic rods has been obtained along with the expressions for the nonlinear rod coefficients in terms of the fundamental three-dimensional nonlinear elastic constants. The quadratic rod coefficients have been calculated for various orientations

of quartz. A theoretical analysis of mode coupling in thickness-extensional PZT-7A trapped energy resonators has been performed and the complicated multi-peaked mode shapes that have been observed experimentally have been shown to occur in the vicinity of splittings in the frequency spectrum. The growth of three-dimensional wave discontinuities in piezoelectric semiconductors has been analyzed by means of the theory of acceleration waves and the relation to the formation and propagation of acoustoelectric domains with transverse displacement components is indicated.

Recent Publications:

1. "Perturbation Theory for Linear Electroelastic Equations for Small Fields Superposed on a Bias," H. F. Tiersten, Journal of the Acoustical Society of America, 64, 832-837 (1978).

2. "On Integral Forms of the Balance Laws for Deformable Semiconductors," M. F. McCarthy and H. F. Tiersten, Archive for Rational Mechanics and Analysis, 68, 27-36 (1978).

3. "Temperature Derivations of the Fundamental Elastic Constants of Quartz," B. K. Sinha and H. F. Tiersten, Proceedings of the 32nd Annual Symposium on Frequency Control, U. S. Army Electronics Research and Development Command, Fort Monmouth, New Jersey, 150-154 (1978).

4. "Temperature Induced Frequency Changes in Electroded Doubly-Rotated Quartz Thickness-Mode Resonators," H. F. Tiersten and B. K. Sinha, Proceedings of the 32nd Annual Symposium on Frequency Control, U. S. Army Electronics Research and Development Command, Fort Monmouth, New Jersey, 155-161 (1978).

5. "An Analysis of Extensional Modes in High Coupling Trapped Energy Resonators," H. F. Tiersten and B. K. Sinha, 1978 Ultrasonics Symposium Proceedings, IEEE Catalog Number 78CH 1344-ISU, Institute of Electrical and Electronics Engineers, New York, 167-171 (1978).

6. "On the Temperature Dependence of the Velocity of Surface Waves in Quartz," B. K. Sinha and H. F. Tiersten, 1978 Ultrasonics Symposium Proceedings, IEEE Catalog Number 78CH 1344-ISU, Institute of Electrical and Electronics Engineers, New York, 662-666 (1978).

7. "On the Influence of a Flexural Biasing State on the Velocity of Piezoelectric Surface Waves," B. K. Sinha and H. F. Tiersten, Wave Motion, 1, 37-51 (1979).

8. "First Temperature Derivatives of the Fundamental Elastic Constants of Quartz," B. K. Sinha and H. F. Tiersten, Journal of Applied Physics, 50, 2732-2739 (1979).

9. "Zero Temperature Coefficient of Delay for Surface Waves in Quartz," B. K. Sinha and H. F. Tiersten, Applied Physics Letters, 34, 817-819 (1979).

10. "An Analysis of Contoured Crystal Resonators Operating in Overtones of Coupled Thickness Shear and Thickness Twist," H. F. Tiersten and R. C. Smythe, Journal of the Acoustical Society of America, 65, 1455-1460 (1979).

NR 318-010, University of California, Los Angeles, "Energy Transfer in Disordered Systems, Dynamics of Spin Glasses, Properties of Granular Superconductors, Superconducting Response Times, and Theoretical Studies of Nematic Polymers, Colloidal Crystals, Unsaturated Polyelectrolytes, and Phospholipid Monolayers", P. I. - Raymond Orbach and Philip Pincus, (213) 825-4281 and (213) 825-5224, N00014-75-C-0245

Research during this period centered on the dynamics of spin glasses near the glass temperature, explicit calculations of phonon assisted transfer in disordered systems, and the dynamic response properties of superconductors. It was found that the spin glass magnetic susceptibility was frequency independent near the glass temperature, indicating that a true phase transition took place rather than a freezing of different sized clusters. Tunneling studies showed the explicit temperature dependence of the spin glass order parameter in the vicinity of the glass temperature for the first time. Phonon assisted transfer rates were calculated for optical systems, with attention paid to amorphous hosts. A new mechanism for the homogeneous linewidth, and relaxation times, of centers in glasses was proposed. The physical significance of the branch imbalance rate in non-equilibrium superconductivity was presented, along with the first detailed calculation of the pair susceptibility for superconductors near the transition temperature. The effects of microwaves on the superconducting energy gap were probed using tunneling techniques. Critical current enhancement was observed, with no evidence for gap enhancement. Progress: A model for a cooperative helix-coil-nematic transition applicable to polypeptide solutions has been studied. Excluded volume interactions in the presence of a general cooperativity parameter for the helix-coil transition have been included. As a first step towards the study of flow-induced transitions, we have considered the modifications of the helix-coil transitions in isolated molecules induced by longitudinal velocity gradients. The phase diagram of ionomers (ion carrying polymers with a small fraction of polar groups) has been examined with emphasis on the sol-gel transition. We have explicitly demonstrated that naive scaling laws may lead to incorrect results for physical properties such as the neutron structure factor and the thermoelectric power in polyelectrolyte solutions. The existence of low frequency propagating shear waves in ordered suspensions of charged latex spheres has been predicted. We are extending these studies to colloidal latex glasses (the so-called Wigner glass). We have begun a theoretical investigation of the phase diagram of the colloidal crystals employing the Ramikrishan-Yousoff theory of freezing and the Platzman-Fukuyama renormalized elastic constants theory for the structural (fcc - bcc) phase transition. L. Turkevich in our group has applied the Kosterlitz-Thouless ideas on vortex induced phase transitions to superconducting thin films. He predicts a Gaussian form for the resistivity in the vicinity of the vortex depairing temperature.

Recent Publications:

1. "Time-dependent spectral transport: a Monte Carlo study", by R. M. Rich, S. Alexander, J. Bernasconi, T. Holstein, S. K. Lyo, and R. Orbach, Physical Review, B18, 3048-3053 (1978).

2. "Mode propagation in superconductors near T_c", by Ora Entin-Wohlman and R. Orbach, Annals of Physics, 116, 35-75 (1978).

3. "Susceptibility of a thin-film spin glass", by I. N. Ibrahim, E. Chock, R. Orbach, and I. Schuller, Physical Review, B18, 3559-3561 (1978).

4. "Spin-flip scattering time of a spin glass", by I. Schuller, R. Orbach, and P. Chaikin, Physical Review Letters, 41, 1413-1417 (1978).

5. "Optical energy transfer in disordered systems", by T. Holstein, S. K. Lyo, and R. Orbach, Comments on Solid State Physics, 8, 119-128 (1978).

6. "Coupled electron spin resonance of non S-state impurities in metals", by S. A. Dodds and T. Plefka, Physical Review, B18, 5977-5980 (1973).

7. "System for the measurement of fast response times under fast electromagnetic irradiation", by I. Schuller, M. Clark, J. Berman, and K. E. Gray, Journal of Physics E12, 263-265 (1979).

8. "High-frequency ac susceptibility and ESR of a spin-glass", by E. D. Dahlberg, M. Hardiman, R. Orbach, and J. Souletie, Physical Review Letters, 42, 401-404 (1979).

9. "The low temperature electronic specific heat of disordered one dimensional chains", by P. S. Riseborough, Solid State Communications, 29, 649-652 (1979).

10. "Energy transfer in random systems", by T. Holstein, S. K. Lyo, and R. Orbach, Journal of Luminescence, 18/19, 634-638 (1979).

11. "Anomalous spin-flip scattering rate near the magnetic-ordering temperature", by P. S. Riseborough, Physical Review, B19, 4677-4683 (1979).

12. "Effect of pair breaking on branch relaxation in nonequilibrium superconductors", by Ora Entin-Wohlman and R. Orbach, Physical Review, B19, 4510-4513 (1979).

13. "Microwave-induced effects on superconductors", by E. D. Dahlberg, R. Orbach, and I. Schuller, Journal of Low Temperature Physics, 36, 367-380 (1979).

14. "Nematic polymers", by P. Pincus and P. G. deGennes, Journal of Polymer Science, 65, 85-90 (1978).

15. "Polyions trapped at an oil-water interface", by P. Pincus, Journal of Colloid and Interface Science, 63, 561-566 (1978).

16. "Nematic polymers: excluded volume effects", by Y. Kim and P. Pincus, ACS Symposium series, No. 74, 127-135 (1978).

17. "Osmotic compressibility of partially deuterated polymer solutions", by S. Alexander and P. Pincus, Polymer, 20, 277-280 (1979).

18. "Nematic polymers: excluded-volume effects", by Y. H. Kim and P. Pincus, Biopolymers, 18, 2315-2322 (1979).

19. "Resistivity of superconducting films", by L. A. Turkevich, Journal of Physics, C12, L385-L388 (1979).

NR 318-023, The American University, "Magnetostrictive Rare Earth-Iron Transducer Materials", P. I. - Earl Callen, (202) 686-2549, N00014-75-C-0736

The rare earth-iron intermetallic compounds (e.g., $TbFe_2$) have enormous room temperature magnetostriction (and enormous magnetic anisotropy). By combining rare earths of the same sign of magnetostriction, but of opposite signs of anisotropy, one can obtain moderately "easy" materials of huge magnetostriction. Also in amorphous materials (in which one is also not limited by solid solubility), one can attain high magnetoelastic response at reasonable signal and bias field strengths. So one would like to understand the magnetic structure and the static and dynamic magnetic and magnetoelastic responses of polycrystalline and amorphous multicomponent (i.e., "ferrimagnetic") systems. Progress: Much of our work over the past two years has been devoted to ultrasonic propagation studies. We have observed two magnetoelastic modes of radically different sound velocities, whose velocities are tunable in a magnetic field, and we have been able to explain the nature of these modes. Now we are back at examining the magnetic structures themselves, and the response to a magnetic field. In an amorphous "ferrimagnetic" two-component system with magnetic anisotropy, the ions of each component tend to fan out over their respective hemispheres. Application of a magnetic field closes in the cone of the dominant moment and opens that of the generally anti-parallel lesser moment, up to a lower critical field. Between lower and upper critical fields the two sets of moments rotate in the field in a complex fashion. Above the upper critical field both sets of moments are fanned around the field directions, their comes closing as the field is increased. The angles of the individual moments to the field and to their local easy axes should be decipherable by Mossbauer spectroscopy. In the coming year we are going to try to use this tool. We shall begin with a learning problem, a single crystal, nearly compensated ferrimagnet in a magnetic field. If we can analyze the data to reveal the angles in this simple case, we shall move on to polycrystalline and amorphous samples of real interest.

Recent Publications:

1. "Resonant Coupling of Shear Waves in Magnetostrictive Rare Earth-Iron Compounds", Stefano Rinaldi and James Cullen, Phys. Rev. B18 3677 (1 October, 1978).

2. "Ultrasonic Studies Below T_c in Amorphous Rare Earth-Iron Alloys", K. Hathaway, M. Melamud, J. Cullen, and G. Blessing, J. Appl. Phys. 50 (3), (March 1979), 1636, (MMM Conf. November, 1978 Cleveland).

3. "Magnetic Structure Changes in Amorphous $ReFe_2$ Alloys as Detected by Ultrasonic Measurements", M. Melamud, K. Hathaway, J. Cullen, Physics Letters (to appear).

4. "Magnetic Field and Temperature Dependence of the Velocity of Sound in $Tb_3Dy_7Fe_2$", M. Melamud, K. Hathaway, J. Cullen, J. Appl. Phys. (to appear). (MMM Conf., July, 1979, New York).

5. "Magnetoelasticity and Moment Rotation in Amorphous Rare Earth-Iron Alloys", J. Cullen, H. Alperin, M. Melamud, K. Hathaway, J. Rhyne, ICM '79, Munich, September, 1979. 1979 International Conference on Magnetism, Conference Proceedings (to appear).

6. "Amorphous Ferrimagnets in Large Magnetic Fields", K. Hathaway and E. Callen, 1979 International Conference on Magnetism, Conference Proceedings (to appear).

NR 318-028, University of Pennsylvania, "Experimental Studies of Graphite Intercalated with Nitric Acid", P. I. - J. E. Fischer, (215) 243-6924, N00014-75-C-0751

Graphite intercalation compounds are a large class of quasi-two dimensional synthetic metals, in which monolayers of foreign atoms or molecules diffuse into the van der Waals gaps between carbon layers. The metallic behavior results from charge transfer between the host graphite and the intercalated species. The ultimate goal is to understand the detailed correlation between electronic properties and crystal structure/chemical composition. The emphasis is on elucidating the one-electron properties and identifying the electronically active species. A variety of optical spectroscopic methods are used to a) study the c-axis charge distribution in dilute compounds; b) characterize the metallic state via the free carrier plasma resonance; c) determine the frequency-dependent dielectric function as a test of band structure calculations and d) perform quantitative chemical analysis to identify the intercalation reaction mechanism and to evaluate the fractional ionization of intercalated molecules. Progress: Using numerical derivative reflectivity spectra, we looked for Burstein-Moss shifts of low-energy interband transitions as a function of the "stage" of intercalation. In pure graphite these transitions occur at 0.74 and 0.88 eV, with E_F as final and initial state, respectively. For both donors and acceptors, the two peaks remained at their graphite values with increasing concentration, finally disappearing at stage 3 or 4. This means that most of the transferred charge resides on the C layers flanking the intercalant layer. Ultraviolet adsorption spectroscopy gave a quantitative analysis of NO_2 evolved during exposure of graphite to HNO_3 vapor. The presence of graphite shifts the equilibrium $2HNO_3=2H_2O+NO_2+NO_3$ strongly to the right. We find one ion per 4 neutrals, or a fractional ionization f=0.2. We conclude that all of the transferred charge is delocalized on the carbon sheets and thus contributes to the metallic properties in the basal plane direction.

Recent Publications:

1. "Charge Transfer in graphite Nitrate and the Ionic Salt Model", S. Loughin, R. Grayeski and J. E. Fischer, J. Chem. Phys. 69, 3740 (1978).

2. "Acid Salts of Graphite: Large or Small Fractional Ionization?", J. E. Fischer, J. Chem. Soc. Chem. Comm. 544 (1978).

3. "Low Energy Optical Transitions in Intercalated Graphite", C. C. Shieh, R. L. Schmidt and J. E. Fischer, Phys. Rev. B20, (1978).

4. "in situ Reflectivity Studies of Donor and Acceptor Intercalated Graphite Compounds", C. C. Shieh, R. L. Schmidt and J. E. Fischer, 14th Biennial Conference on Carbon: Extended Abstracts, 290 (1979).

5. "Graphite Intercalation Compounds", J. E. Fischer and T. E. Thompson, Physics Today, 31, 36 (1978).

6. "Electronic Properties of Graphite Intercalation Compounds", chapter in Physics and Chemistry of Materials with Layered Structures, (F. Levy, editor) D. Reidel, Holland (1979).

7. "Anisotropy of Graphite Intercalation Compounds", J. E. Fischer, in Molecular Metals (W. E. Hatfield, editor), Plenum Press, New York, 281 (1979).

8. "Graphite Intercalation Compounds: An Overview", Comments in Solid State Physics, 8, 155 (1978).

9. "Intercalated Graphite: Some Aspects of Two-Dimensionality", Comments in Solid State Physics (in press).

NR 318-039, North Texas State University, "Investigation of Optical Biasing on the Quantum Transport Properties of Semiconductors," P. I. - Dr. David G. Seiler, (817) 788-2626, N00014-76-C-0319

The primary goal of this research is to investigate the interaction of CO and CO_2 laser radiation with semiconductors. Quasi-steady state optical biasing of the conductivity is being investigated in the presence of high electric and magnetic fields. In addition, the nonequilibrium and relaxation properties of semiconductors are being ascertained through the use of an electro-optic switch which provides fast rise and fall time laser pulses ($\leq$30 nsec). During this study, new tools are being developed and utilized to provide information on (1) the non-equilibrium electron temperatures and distributions; (2) the effect of the laser irradiation; (3) the nature and corresponding times of the energy relaxation mechanisms. Progress: Both the Shubnikov-de Haas effect and the photoconductivity have been utilized to determine electron temperatures for both CO and CO_2 laser radiation at various laser frequencies and powers for n-InSb samples of different electron concentrations. Free carrier absorption of tuned CO_2-laser radiation was shown to be a valuable new tool for the extraction of information on photoheated hot carriers and free carrier absorption coefficients in degenerate n-InSb at liquid helium temperatures. This new technique exploits parallel photoheating and dc electrical-heating experiments. The CO laser hot electron studies have provided information on the nature of the absorption processes near the bandgap of n-InSb and their relationship to carrier heating effects. We have discovered sensitive photoconductive effects in n-InSb at the medium infrared wavelengths near 10 microns where the CO_2 laser-induced magneto-photoconductivity has been shown to exhibit a number of very sharp resonances whose positions depend strongly upon photon energy. The results directly show that the intraband magneto-optical transitions involve up to five longitudinal optical phonons. All observed transitions can be described with one single set of band parameters.

Recent Publications:

1. "New Hybrid Photoconductivity Technique for the Investigation of CO_2-Laser Induced Hot-Carrier and Free Carrier Absorption Effects in Degenerate n-InSb at 1.8 K," D. G. Seiler, J. R. Barker, and B. T. Moore, Phys. Rev. Letters 41, 319 (1978).

2. "Shubnikov-de-Haas Effect Studies on Optically Heated Electrons in n-InSb," D. G. Seiler, L. K. Hanes, M. W. Goodwin, and A. E. Stephens, J. of Mag. and Mag. Materials 11, 247 (1979) Also presented at the International Conference on Solids and Plasmas in High Magnetic Fields, MIT, Cambridge, Mass.

3. "Absorption Processes Near the Bandgap of InSb: Laser-Induced Hot Electron and Photoconductivity Studies," D. G. Seiler and L. K. Hanes, Optics. Commun. 28, 326 (1979).

4. "Photoconductivity of Laser Excited Hot Electrons in Degenerate n-InSb," D. G. Seiler, J. R. Barker, B. T. Moore, K. E. Hansen, in Proceedings of the 14th Int. Conf. on the Phys. of Semiconductors, Edinburgh, 1978 (The Institute of Physics, London, 1979), p. 501.

NR 318-041, Emory University, "Far Infrared Optical Studies of Semiconductors," P. I. - Dr. Sid Perkowitz, (404) 329-6584, N00014-76-C-0429.

Far Infrared and infrared optical measurements are used to investigate III-V, II-VI and chalcopyrite semiconductors and their alloys. The data yield electronic, lattice and band information and also give a means to characterize epitaxial layers. Progress: A complete lattice analysis for InGaAsP has been carried out as has a complete interface analysis for InAs/GaAs. Earlier anomalous results in HgMnTe near the cross-over point appear to be due to resonant acceptor levels. A detailed analysis is proceeding. Non-linear measurements near 10.6 μm are underway for HgCdTe. A spectroscopic study and phonon analysis for the chalcopyrite $CuInTe_2$ has been initiated. An initial effort in far infrared photoacoustic spectroscopy in semiconductors has been completed and has led to a feasibility estimate for the technique and the development of improved spectroscopic instrumentation.

Recent Publications:

1. "Far Infrared Spatial Probe of Heteroepitaxial Indium Arsenide," P. M. Amirtharaj and S. Perkowitz, Thin Solid Films 62, 357 (1979).

2. "Far Infrared Spectroscopy of InGaAsP," P. M. Amirtharaj, R. E. Hayes, and S. Perkowitz, Bull. Am. Phys. Soc. 24, 311 (1979).

3. "Far Infrared Spectroscopy of III-V Epitaxial Surface and Interfaces," ibid., p. 277.

4. "Far Infrared Spectroscopy of InGaAsP," P. M. Amirtharaj, D. G. Holah, and S. Perkowitz, Conference Digest of the IVth International Conference on Infrared and Millimeter Waves, Miami, 1979, S. Perkowitz, Editor (IEEE, New York, 1979), p. 189.

5. "Optically pumped FIR Laser Monitored by Piezoelectric Transducers," G. Busse and S. Perkowitz, ibid., p. 69.

NR 318-048, North Texas State University, "Optically Induced Hot Electron Effects in Semiconductors," P. I. - Dr. Arthur L. Smirl, (817) 788-2626, N00014-76-C-1077

The investigator will use the high electric fields and the ultrashort pulses that can be derived from mode-locked lasers to study the saturable optical transmission properties and hot electron dynamics of semiconductors on a picosecond time scale. In these studies, variations of the excite and probe technique will be used to obtain direct information concerning ultrafast relaxation processes of photogenerated carriers. Progress: Among other studies, we have previously irradiated thin ($\sim$5 μm) germanium samples with an intense excite pulse at 1.06 m. The absorption of the excite pulse creates a large, rapidly evolving, nonequilibrium carrier distribution that changes the transmission properties of the sample. This initial pulse is then followed at various time delays by a weak probe pulse of the same wavelength that monitors the evolution of the enhanced germanium transmission with time. A graph of the probe pulse transmission versus time exhibits two distinct features. The first is a rapid rise and fall in the probe transmission that is approximately two picoseconds wide and is centered about zero delay. This pike is followed by a gradual rise and fall of the probe transmission lasting hundreds of picoseconds. At least two possible explanations have been suggested for the narrow spike in probe transmission and three explanations for the slower rise and fall in probe transmission lasting hundreds of picoseconds. The narrow spike in probe transmission centered about zero delay has been attributed (1) to a parametric scattering of the excite beam into the probe beam path by a grating formed in the germanium by the interference of the two pulses near zero delay and (2) to state-filling and band-gap narrowing. The slow rise in probe transmission has been attributed (1) to bandfilling, (2) to a cooling of a hot carrier distribution created by direct absorption of the excite pulse, and (3) to Auger recombination combined with an absorption versus carrier density relationship containing a minimum. We have recently concluded three separate experimental studies that (i) demonstrate that the slow rise in probe transmission at 100 K is not an integration effect caused by band-filling, (ii) indicate that this slow rise is not caused by carrier recombination combined with an absorption vs. density curve containing a minimum, and (iii) provide evidence that the narrow spike at zero delay is a correlation effect.

Recent Publications:

1. "Ultrafast Transient Response of Solid State Plasmas: I Germanium: Theory and Experiment," Ahmet Eleci, M. O. Scully, A. L. Smirl, and J. C. Matter, Phys. Rev. B. 16, 191 (1977).

2. "Pulsewidth Dependence of the Transmission of Ultrashort Optical Pulses in Germanium," John S. Bessey, Bruno Bosacchi, Henry M. van Driel, and Arthur L. Smirl, Phys. Rev. B 17, 159 (1978).

3. "The Role of Phonons and Plasmons in Describing the Pulsewidth Dependence of the Transmission of Ultrashort Optical Pulses through Germanium," W. P. Latham, Jr. A. L. Smirl, A. Elci, and J. S. Bessey, Solid-State Electron. 21, 159 (1978).

4. "Physics of Ultrafast Phenomena in Solid State Plasmas," A. Elci, A. L. Smirl, C. Y. Leung, and M. O. Scully, Solid State Electron. 21, 151 (1978).

5. "Gauge Invariant Perturbation Theory for the Interaction of Radiation and Matter," Donald H. Kobe and Arthur L. Smirl, Am. J. Phys. 46, 624 (1978).

6. "Simple Laser Pulse Energy Monitor," A. L. Smirl, R. L. Shoemaker, J. B. Hambenne, and J. C. Matter, Rev. Sci. Instrum. 49, 672 (1978).

7. "Picosecond Optical Measurement of Free-Electron, Free-Hole and Indirect Absorption in Germanium at High Optically-Created Carrier Densities," Arthur L. Smirl, J. Ryan Lindle, and Steven C. Moss, Phys. Rev. B 18, 5489 (1978).

8. "Picosecond Optical Absorption at 1.06 μm and 1.55 μm in Thin Germanium Samples at High Optically-Created Carrier Densities," Arthur L. Smirl, J. Ryan Lindle, and Steven C. Moss, Proceedings of the Conference on Picosecond Phenomena, 174, Springer-Verlag (1978).

9. "The Effects of Parametric Scattering, Energy-Gap Narrowing, and State Filling on the Picosecond Optical Response of Germanium," J. Ryan Lindle, Steven C. Moss, and Arthur L. Smirl, Phys. Rev. B, Sept. 1979.

NR 318-049, University of California at Los Angeles, "Macromolecular and Colloid Physics: Polyelectrolytes, Iomomers, Nematic Polymers, Wormlike Chains, Colloidal Crystals and Ferrofluids," P. I. - Dr. Paul Chaiken and Dr. Philip Pincus, N00014-76-C-1078

This research represents a joint experimental-theoretical program in the physics of macromolecular and colloidal systems. The principal focus will be the application of contemporary physical techniques (scattering by neutrons, x-rays, and light, optical and transport measurements, scaling and renormalization group approaches) to investigate the conformations and dynamics of solutions and suspendions having novel electrical and magnetic characteristics.

The work is divided into two rather distinct parts: A) Colloids and B) Polymers.

A) Colloids. The colloid effort is to be bifurcated into two subsections: A) Colloidal Crystals and b) Ferrofluids. a) Polystyrene sphers (diameters from 0.1 μ to 10 μ) are available with sulfonic acid groups attached to the surface leading to approximately 10^3 charges/sphere when suspended in an aqueous solution. Under the influence of

the Coulomb repulsions, the system crystallizes into a "classical Wigner crystal." We are studying the various "solid state" phase transitions, possible phase separation, and dynamics. Similar behavior is to be found in rod-like (TMV) virus suspensions. b) Ferrofluids are colloidal suspensions of subdomain size (~100 Å) magnetic particles, e.g. magnetite usually in oil carriers. Macromolecular surfactants or polymer sheaths are attached to the surface to prevent aggregation. Such magnetic fluids have application to rotary seals, speaker fluids, material separators etc. One problem is to increase the magnetization while preventing phase separation.

B) Polymers. The polymer solution research is subdivided under five general headings: a) ionomers, b) worm-like chains, c) polyelectrolytes, d) nematic polymers, e) magnetically doped polymers. a) ionomers are copolymers where a fraction of the monomers are decorated with ionizable groups. If this fraction is not too large the polymers may be soluble in non-polar solvents with an electric dipole-dipole interaction coupling the decorated monomers. Such systems (e.g. sulfonated polystyrene) may gel under the influence of the dipolar terms. We are studying the phase diagram associated with this reversible gelation and related physical properties such as viscosity and dielectric relaxation. b) Worm-like chains are linear polymers which are flexible on a long scale but possesss short range rigidity arising from energetically preferred rotational isomers. The conformations and dynamics of such chains are studied as a function of solvent quality by means of de Gennes-type scaling relations. c) Polyelectrolytes are aqueous solutions of polymers with essentially all monomers carrying ionizable groups. In solution, the system is effectively a gas of small counterions in the presence of highly charged polymers. We have been studying the conformations of these systems where Coulomb interactions dominate as functions of concentration and ionic strength. d) Nematic polymers are chains which are sufficently still to form liquid crystalline orientational order. An example of this behavior is given by polypeptides such as PBLG which form helicies. We are studying the phase diagram of polypeptide solutions in the temperature-concentration plane taking into account "induced rigidity" introduced by de Gennes and Pincus and in the presence of both velocity gradients and polar attractions.

Recent Publications: New Contract

NR 318-050, Yale University, "The Metallic Regime of Silicon Inversion Layers-Energy Levels and Transport Processing," P. I. - Robert G. Wheeler, (203) 436-4275, N00014-76-C-1083.

The general aim of this research is to characterize the physics of the two-dimensional gas as embodied in the inversion layer of silicon field effect transistors. Our particular interest is centered upon elucidation of the electron-phonon coupling. There are a large number of experiments including warm electron effects, photoconductivity, and indeed mobility at low temperatures, which depend critically upon the detailed mechanism of energy relaxation. Progress: During the current year we have made

an extended series of warm electron experiments which when analyzed in terms of three-dimensional phonons has led to inconsistencies in terms of theoretical expectations. We have taken the view that these results are consistent with a two-dimensional phonon system. With this conjecture we are currently completing a series of mobility measurements carried down to .9°K in order to confirm a T^4 dependence, a signature consistent with a two-dimensional phono system (T^5 is consistent with a three-dimensional system). Upon completion of these experiments, we will turn to the warm electron system. Here we desire to fabricate devices which will allow us to determine the characteristic mean-free paths of phonons as limited by the electron-phonon system. It is our goal to be able to describe the spatial form of the phonons which interact with the electron gas.

Recent Publications:

1. "Photoconductivity Measurements Related to Intersubband Transitions in Silicon MOSFET Structures," C. C. Hu, J. Pearse, K. M. Cham, and R. G. Wheeler, Surface Science 73, 207 (1978).

2. "Electron-Phonon Interactions in n-type Silicon Inversion Layers at Low Temperatures," K. M. Cham and R. G. Wheeler, Proceedings of the Third International Conference on Electronic Properties of Two-Dimensional Systems, 236 (1979).

NR 318-052, Massachusetts Institute of Technology, "Graphite Intercalcation Compounds," P. I. - Dr. Mildred Dresselhaus, N00014-77-C-0053, 617-253-6864

In this program, the mechanism of graphite intercalation will be studied using Raman and IR spectroscopy, and models for lattice dynamics will be deduced from these measurements. These spectroscopic techniques are especially valuable for studying the intercalation mechanism because each of three types of layers (the intercalate layers, the graphite bounding layers adjacent to the intercalate layer, and the graphite interior layers that are not adjacent) can be investigated independently due to their different mode frequencies. The intercalation mechanism is believed to be related to lattice strain (rather than an electronic mechanism), so that by probing the in-plane force constants in each type of layer, this hypothesis can be tested. With our recent acquisition of an infrared Fourier transform spectrometer, a detailed study of the dependence of infrared spectra on stage and intercalate species will be carried out. Particular attention will be given to the use of infrared spectroscopy to monitor the intercalation process dynamically. The lattice dynamics will be modelled by both a perturbation theory which explicitly considers the coupling between the graphite bounding layer and intercalate layer modes and by a full zone Born-von Karman expansion for phonons. In the latter treatment, zone folding and lattice strain will also be introduced. The experimental mode positions and frequency shifts will be used to determine the coupling coefficients explicitly. Progress: The stage dependence of Raman spectra associated with the graphitebounding and interior layers has been determined for a number of acceptor intercalants, including $FeCl_3$, $AlCl_3$ and Br_2. For all acceptors, similar upshifts in

the Raman-active mode frequencies are observed with increasing intercalate concentration (decreasing stage), in contrast to the behavior for donor compounds where a frequency downshift is observed. Interpretation of these Raman results in terms of a strain mechanism implies that intercalation gives rise to an in-plane lattice expansion in the case of donors and a contraction in the case of acceptors. This interpretation is supported by (1) x-ray measurements of the stage dependence of the in-plane lattice constant in the donor graphite-potassium system and (2) preliminary stage-dependent IR-active mode frequency measurements in donor and acceptor compounds.

Recent Publications:

1. "In-Plane Intercalate Lattive Modes in Graphite-Bromine Using Raman Spectroscopy," P. C. Eklund, N. Kambe, G. Dresselhaus and M. S. Dresselhaus, Phys. Rev. B18, 7069 (1978).

2. "Lattice Mode Structure of Graphite Intercalation Compounds," M. S. Dresselhaus and G. Dresselhaus, Physics and Chemistry of materials with Layered Structures, Vol. 6: Intercalation Compounds (ed. F. Levy), D. Reidel, Dordrecht, Holland.

3. "Lattice Modes in Layered Graphite-Ferric Chloride," C. Underhill, S. Y. Leung, G. Dresselhaus and M. S. Dresselhaus, Institute of Physics Conference Series 43, (ed. B. L. H. Wilson), 1978, p. 887.

4. "Infrared and Raman Spectroscopy of Graphite-Ferric Chloride," C. Underhill. S. Y. Leung, G. Dresselhaus and M. S. Dresselhaus, Solid State Commun. 29, 769 (1979).

5. "Raman Scattering in Stage 2 Graphite-Bromine," C. L. Lau and M. S. Dresselhaus (accepted for publication in Phys. Rev.).

6. "Raman and Infrared Spectra of Graphite $AlCl_3$", G. M. Gualberto, C. Underhill, S. Y. Leung and G. Dresselhaus (accepted for publication in Phys. Rev.).

NR 318-053, University of Rochester, "Experimental Studies of Cooperative Phenomena," P. I. - Ronald D. Parks, (212) 643-2071, N00014-75-C-0566.

Studies are made of magnetism in the presence of various competing mechanisms: (1) the interplay of surface ferromagnetism and surface segregation in binary alloys, (2) the interplay of ordered magnetism and Kondo-like spin fluctuations in Anderson lattice systems, and (3) frustrated ferromagnetism and spin glass behavior in random systems with both ferromagnetic and antiferromagnetic interactions. In problem area (1), surface segregation is studied by means of Auger spectroscopy in various transition metal alloys with Curie temperatures above 500 C, where equilibration times are rapid. Ordered magnetism is studied in Anderson lattice systems (e. g., $CeAl_2$) by neutron diffraction and other experimental techniques as a function of the spin fluctuation temperature, which can be altered by chemical alloying. In problem area (3), current attention is focused on the system $Cr_{1-x}Fe_x$, which for a limited concentration

range, $0.2 < x < 0.3$, exhibits ferromagnetism which becomes increasingly frustrated with decreasing temperature, leading finally to a spin-glass-like state. Experimental techniques employed include both quasielastic and inelastic neutron scattering, mossbauer spectroscopy and magnetization measurements. Progress: (1) An Auger measurement of the composition of the top few monolayers of polycrystalline $Ni_{1-x}Cu_x$ with $0.02 < x < 0.05$ revealed a plummeting of the Cu concentration (nominally $\sim$ 50%) at the surface as the temperature is lowered below the bulk ferromagnetic transition temperature. This suggests for the first time the interplay between surface segregation and surface magnetism in a binary system. (2) In $CeAl_2$ the magnetism is weakened by Kondo-like fluctuations. This is manifested in an unusual topology of the ordered magnetism in which there is a long wavelength modulation of not only the direction of the individual spins but their magnitude as well. An added feature of the ordered state recently revealed by careful neutron diffraction studies is that the state is a triple-q state, such states having been predicted by renormalization group studies but never before definitively demonstrated experimentally. (3) Quasielastic neutron scattering studies of $Cr_{1-x}Fe_x$ in the concentration range $0.2 < x < 0.3$ revealed on increase in the finite q scattering with decreasing temperature, and inelastic neutron scattering studies revealed a softening of the spin wave stiffness coefficient with decreasing temperature.

Recent Publications:

1. "Thermal Expansion in the Anderson Lattice System, $CeAl_2$," M. C. Croft, I. Zoric and R. D. Parks, Phys. Rev. B 18, 5065 (1978).

2. "Resistance Anomaly at the Order-Disorder Transition in Fe_3Al," D. Chakraborty and R. D. Parks, Phys. Rev. B 18, 6195 (1978).

3. "Ground State Properties and Energy Parameters of the Anderson Lattice System, $CeAl_2$," R. D. Parks, L. C. Kupferberg, M. A. Manheimer, S. M. Shapiro and E. Gurewitz, J. Phys. (France) 40, C5-323 (1979).

4. "Evidence of a Multiple q Structure in $CeAl_2$," E. Gurewitz, S. M. Shapiro, L. C. Kupferberg and R. D. Parks, J. Appl Phys. 50, 2014 (1979).

5. "Magnetic Moment Reduction in the Anderson Lattice System, $CeAl_2$: Pressure Effects," M. C. Croft, R. P. Guertin, L. C. Kupferberg and R. D. Parks, Phys. Rev. B 20, 2073 (1979).

NR 318-055, Massachusetts Institute of Technology, "Surface and Defect Excitations in Covalently Bonded Solids," P. I. - J. D. Joannopoulos, (617) 253-4806, N00014-77-C-0132.

A detailed theoretical study of the nature, character and localization of vibrational and electronic excitations at surfaces and interfaces of SiO_2 and Si will be performed. These systems are very difficult to study because the intrinsic disorder at surfaces and interfaces of SiO_2 implies that there are regions where bonding is ideal, regions where bonds are distorted and regions where bonds are actually broken. All three types

of regions must be included in a realistic theory and it would be of great advantage to somehow isolate these regions and study them separately. This can, in fact, be accomplished with realistic tight-binding Hamiltonians (or force constant models) using the cluster-Bethe-lattice-method developed earlier by the P. I.. The method entails modelling the surface as a Bethe-lattice with a dangling bond and treating the two-dimensional nature of the surface and the surface topography as small perturbations. Interfaces can then be modelled by connecting different Bethe-lattice surface systems together. The method emphasizes the local structure at a surface or interface.
Progress: Theoretical calculations of IR and Raman spectra have been used to predict and understand surface phonon structure in experimental measurements of porous SiO_2. Both surface acoustical and short-wavelength surface optical phonons and their interactions with adsorpates were studied. The IR and Raman spectra for surface O atmos were found to be quite different from expected simple molecule considerations. In addition, various surprising results concerning chlorination were obtained and an interface phonon in SiO_2-Si predicted.

A new tight-binding Hamiltonian has been introduced which describes realistcally both the valence bands and low-lying conduction bands of SiO_2. Studies on bulk SiO_2 predict that optical transitions from the upper-most valence states to the low-lying conduction states will always be dipole-forbideen, independently of the particular structure of SiO_2, be it crystalline or amorphous.

Recent Publications:

1. "Intrinsic Surface Phonons in Porous Glass," R. Laughlin, J. Joannopoulos, C. Murray, K. Hartnett and T. Greytak, Phys. Rev. Lett. 40, 461 (1978).

2. "Effects of Three-Body Interactions on the Vibrations of Amorphous SiO_2," R. Laughlin and J. Joannopoulos, Phys. Rev. B 17, 2790 (1978).

3. "Theory of Surface Phonons in Amorphous Silica," R. Laughlin and J. Joannopoulos, Phys. Rev. B 17, 4922 (1978).

4. "Electronic Structure of Crystalline and Amorphous SiO_2," D. Chadi, J. Joannopoulos and R. Laughlin, Proc. of Int. Conf. on Physics of SiO_2 and its Interfaces, IBM, Yorktown Heights, p. 55 (1978).

5. "Electronic States of Si-SiO_2 Interfaces," R. Laughlin, J. Joannopoulos and D. Chadi, Proc. of Int. Conf. on Physics of SiO_2 and its Interfaces, IBM, Yorktown Heights, p. 321 (1978).

NR 318-058, Princeton University, "Correlation, Disorder, and Noise in Electronic Systems: Metal-Insulator Transitions in Semiconductors," P. I. - Dr. D. C. Licciardello, N00014-77-C-0711, (609) 452-5856

A program of basic research into the electronic structure of non-crystalline systems will be carried out. The fundamental processes in such systems determine the electronic properties of a wide range of

materials from window glass to sophisticated semiconducting devices, e.g. MOSFETS. We continue to expand research into the theory of random systems; to understand more specifically the mechanisms for various transport phenomena, the temperature dependence as well as ground state properties, noise characteristics including the ubiquitous 1/f noise present, for example, in doped semiconductors, and the critical properties associated with disorder or correlation induced metal - insulator phase transitions. Progress: A scaling theory was proposed by E. Abrahams, P. W. Anderson, D. C. Liccidardello, and T. V. Ramakrishnan, which almost immediately received experimental confirmation by Dolan and Osheroff and by Bishop and Dynes. The new and exciting result of the scaling theory is that localization is universal in two as well as one dimension, and that this is easily observed as a logarithmic dependence of the resistance on temperature for thin films.

We (with D. Stein) developed a phenomenological model of amorphous semiconductors which accepts as its basic premise a statistical distribution of Anderson negative-U centers. The model is shown to predict a photo-induced optical absorption spectrum with an edge at $E_g/2$ where E_g is the ground state gap. We have also generalized the model to take account of phonon-sharing, i.e. phonon size effects.

Recent Publications:

1. "Scaling Theory of Localization Absence of Quantum Diffusion in Two Dimensions" by E. Abrahams, P. Anderson, D. Licciardello, T. Ramakrishnan, PRL 42 673 (1979)

2. "Optical vs. Transport Processes in Chalcogenide Glasses" by Dr. Licciardello and D. Stein, submitted to Phys. Rev. Letters.

3. "Excitations and Metastability in Amorphous Semiconductors" by D. Licciardello, D. Stein, F. Haldane, Phil. Mag., in press.

4. "Why Do Glassy Materials Possess Energy Gaps?" Comments on Solids State Physics, in press.

5. "Possible Explanations of Nonlinear Conductivity in Thin-Film Metal Wires" by P. Anderson, E. Abrahams, and T. Ramakrishnan, PRL 43 718-720 (1979)

NR 318-059, Naval Research Laboratory, "Oxide-Semiconductor Interface and Dielectric Relaxation Studies," P. I. - Dr. K. L. Ngai, (202) 767-3692, N00014-WR-90028

The fundamental electronic properties of semiconductor-insulator interfaces are of considerable current and future interest for DOD electronic systems. However, the microscopic understanding of the nature and origin of electrically active states at the interface and of their relation to the electrical characteristics remains in a rather primitive state. In addition, some of these interface and oxide properties are related to one of the oldest unsolved problems in condensed matter physics, the low frequency dielectric response. The aim of this theoretical work is twofold:

1) To provide microscopic models of the oxide-semiconductor interface which explain the electrical properties; and 2) to develop a coherent theoretical picture of the low frequency dielectric response of condensed matter. Many-body techniques and a multiband tight-binding cluster-Bethe lattice approach are being used to calculate the electronic properties of dangling and strained bonds at the Si-vacuum and Si-SiO_2 interfaces. Several concepts utilized in other areas of physics have been joined in a novel approach which yields a coherent picture of the dielectric response of condensed matter. This general model will be applied to calculations of 1/f noise, NMR relaxation in polymers and analysis of capacitance studies of deep traps in semiconductors. Progress: Multiband tight-binding cluster calculations have been made to uncover further the origin and nature of the intrinsic interface states at the Si-SiO_2 interface. Results show that distortion (reconstruction) effects are important in the description of these states and that three-fold coordinated Si atoms at the Si-SiO_2 interface as well as strained Si-Si bonds on the oxide "side" of the interface can exist in metastable configurations leading to e.g., device instabilities. A subgroup of these states also provides an explanation for some of the perplexing low temperature measurements on Si inversion layers. It was recently recognized that there exists a remarkable universality of dielectric response behavior in condensed matter regardless of physical structure, types of bonding, chemical type, polarizing species, and geometrical and configurations. We have proposed a corresponding universal mechanism associated with the existence of some ubiquitous very-low-energy excitations. These excitations exhibit an infrared-divergent-like response to transitions of the polarizing species induced by a time-varying electric field in the dielectric and give rise to the universal dielectric response.

Recent Publications:

1. "Model for the Temperature Dependence of the Metastable 2x1 reconstructed Silicon (111) Surface," C. T. White and K. L. Ngai, Phys. Rev. Lett. 41, 885 (1978).

2. "Reconstructing States at the Si-SiO_2 Interface," C. T. White and K. L. Ngai, J. Vac. Sci. and Tech., July/Aug. issue, 1979.

3. "Frequency Dependence of Dielectric Loss in Condensed Matter," K. L. Ngai and C. T. White, Phys. Rev B20, 2475 (1979)

4. "On the Origin of the Universal Dielectric Response of Condensed Matter," K. L. Ngai, A. K. Jonscher, and C. T. White, Nature 277, 185 (1979).

NR 318-060, Indiana University, "Phonon Transport Through Solid Interfaces," P. I. - Dr. Walter E. Bron, (812) 337-1304, (812) 337-9879

Recently developed experimental techniques permit spectral, spatial and temporal resolution of phonon transport in solids and and at solid interfaces. This is in contrast to the traditional thermal conductance and heat pulse methods which yield averages over frequency, space and/or time. Progress:

New experimental results, using a vibronic sideband phonon spectrometer (VSPS), show that phonon transport through solid-solid interfaces is influenced by frequency dependent phonon backscattering across the interface. Such backscattering is shown to result from elastic phonon scattering at isotopic and/or foreign ion imperfections in solids. The effect is shown to cause incremental time-dependent temperature changes in thin, metallic heater films evaporated onto insulator substrate crystals. The results on several substrates are adequately predicted by a new model treatment of the interface transport.

The experimental techniques are also applicable to studies of the frequency dependence of phonon lifetimes in solids. A preliminary investigation of phonon lifetimes in insulator crystals shows a considerable discrepancy between the observed frequency dependence and that predicted by extant theoretical models. Efforts are underway to refine the experimental and theoretical techniques in order to determine the role of crystal anisotropy on the frequency dependence on phonon lifetimes and on phonon reflection from-and transmission through- solid-solid interfaces.

Recent Publications:

1. "Phonon Emission into Diffusive Media", W.E. Bron, to be published in the Proceedings of the III International Conference on Phonon Scattering in Condensed Matter, August 1979, Providence, R.I.

2. "Transport of Phonons into Diffusive Media," W.E. Bron, J.L. Patel and W.L. Scaich, to be published in Phys. Rev. B.

3. "On the Lifetimes of High Frequency Phonons", W.E. Bron, to be published in Phys. Rev. B.

4. "Spectroscopy of High Frequency Phonons", W.E. Bron, prepared for the Reports on Progress in Physics, (accepted for publication).

NR 318-062, University of Houston, "Theoretical Study of the Electronic and Vibrational Properties of Certain Semiconductors", P.I. - Dr. C. S. Ting, (713) 749-2865, N00014-78-C-0508

Several different areas related with either the electronic or the vibrational properties of some semiconductors are proposed to be studied. The first topic is connected with the transport theory of two types of carriers in the Si-surface inversion layer. The transport relaxation time will be studied by using the memory function approach. The second subject is related with the recently observed diamagnetic anomaly in cuprous chloride (CuCl) crystal at temperature $\sim$150K and under $\sim$40 K bar pressure. There has been speculation that this diamagnetic phase may be originated from a possible superconducting phase. Since the bond between nearby atoms in CuCl has a considerable fraction of covalency, this bond may provide a pairing center for two electrons with opposite spin. The role played by these pairing centers on diamagnetism will be carefully examined. In the future we also wish to look into the vibrational and electronic properties of CuCl crystal, GaAs-$Ga_{1-x}Al_xAs$ superlattices and graphite-alkalai compounds. Progress: With regard to the Si-surface inversion layers, we have shown that the effect of Auger-type transition on the optical absorption can considerably broaden the line width of the absorption resonance and shift the position of the resonance. We also made some progress on the calculation of the real and imaginary parts of the memory function due to intervalley electron-electron interactions. The results can be

applied to study the transport properties of electrons in Si (100) surface. The influence of electron pairing centers (-U) to the superconductivity (or ferromagnetism) in non-simple metals has been studied, and our calculation indicates that such negative U centers will enhance the superconducting transition temperature. We believe that this mechanism can be applied to CaH_6 under pressure. During the past year we also did a renormalization group calculation on the phase transition of one-dimensional systems, and the effect of defect on the superconducting transition of A-15 compounds.

Recent Publications:

1. C.S. Ting, S.C. Ying and J.J. Quinn, "The Dynamical Conductivity of Semiconducting Surface Inversion Layer in the Presence of a Magnetic Field", Phys. Rev., B16, 5394 (1977).

2. C.S. Ting and A.K. Ganguly, "Temperature Dependence of Dynamic Conductivity of Electrons in the Surface Inversion Layer of Semiconducting Silicon", Phys. Rev., B16, 3541 (1977).

3. C.S. Ting and J.L. Firman, "X-Point Model for Magnetic Susceptibility of A-15 Compounds", Phys. Lett., 64A, 87 (1977).

4. C.S. Ting, "The Isothermal Pressure Derivative of the Elastic Shear Modulus for V_3Si", High Pressure and Low Temperature Physics, Plenum Pub., 313 (1978).

5. C.S. Ting and C.Y. Huang, "Resistivity Maxima for Certain Magnetic Systems", Solid State Comm., 26, 831 (1978).

6. C.S. Ting, T.M. Snyder and G.J. Williamson, "Saturating Contribution to Electrical Resistivity from Electron-Phonon Interactions in Transition Metal Compounds", Journal of Low Temp. Phys., 36, 531 (1979).

7. S.E. Huang, C.W. Chu and C.S. Ting, "Defect Influence on the T_c of A-15 Compounds", Phys. Rev., B, Sept. 1 (1979).

8. C.S. Ting, and A.K. Ganguly, "Effect of Auger Type Transition on the Intersubband Optical Absorption in Si-Surface Inversion Layer", Phys. Rev., B, Dec. 1 (1979).

NR 313-063, North Carolina State University "Pressure Studies of the Quadrupolar Glass Phase of Solid Hydrogen", David G. Haase, Department of Physics, (919) 737-2512, N00014-79-C-0133

The study of ordering in spin-glass systems, as well as other glasses, is often frustrated by incomplete knowledge of the ordering interactions themselves. It would be beneficial to have a physical glass system, which contained a well described nearest-neighbor interaction, as a beginning point for experimental and theoretical investigations of the basis of glassy behavior. We are measuring the bulk thermodynamic properties of the so-called "Quadrupolar Glass" phase of solid H_2, which does have a well-described intermolecular ordering interaction and which does show glass-like properties. In solid hydrogen the orthohydrogen molecules order through a nearest neighbor electric quadrupole-quadrupole interaction, analogous to the ordering of magnetic ions in a spin glass such as CuMn. In this analogy the non-magnetic species is the non-ordering, spherical parahydrogen molecule. Solid samples of arbitrary orthohydrogen concentration may be grown and measured, and the slow con-

version of orthohydrogen to parahydrogen permits unique measurements of properties as a function of a continuously varied "magnetic" species. The existence of the quadrupolar glass of H_2 was first proposed on the basis of NMR measurements. It is the objective of the present work to determine the specific heat of the glass indirectly through measurements of $\delta P/\delta T)_V$ and relate that behavior to other glassy systems. We are also investigating the phase diagram of the glass state and its remanence properties. Progress: We have completed preliminary studies which show that there is no first or second order phase transition in solid H_2 at the temperatures associated with the NMR glass transition. The specific heat is nearly linearly proportional to temperature, consistent with a glassy phase. The transition line between long range order and glassy disorder has been measured to $0.2^{o}K$. Future work will involve a systematic study of the linearity and orthohydrogen concentration dependence of the specific heat and extension of the experiment to solid D_2.

Recent Publications:

1. "Pressure Measurements of the Solid Hydrogen Quadrupolar Glass", D.G. Haase, R.A. Orban and J.O. Sears, Solid State Communications, Nov. 1979, (in press).

2. "Pressure Transitions in Solid H_2 Below $0.5^{o}K$", D.G. Haase, J.O. Sears and R.A. Orban, (in preparation).

NR 318-064, University of Illinois at Chicago Circle, "Determination of the Temperature Dependence of the Order Parameter in Improper Ferroelectrics by Raman Hard Mode Spectroscopy", P.I. - Paul M. Raccah, (312) 996-3403, N00014-79-C-0486.

The phenomenological Landau theory of phase transitions consists in expressing the free energy describing the system as a power series of an order parameter. Knowledge of the temperature dependence of that order parameter $\eta = (T_c-T)\gamma$ is necessary in order to distinguish between various applicable microscopic models. The soft mode theory has shown that the frequency of the soft mode driving the phase transition obeys the same temperature law as the order parameter. The difficulty is, however, that soft modes are often overdamped or masked by other modes and their study by Raman scattering is often disappointing. More recently it has been proposed that the frequency of a hard mode coupling with the soft mode behaves in temperature like the square of the order parameter. We are presently studying the rare earth molybdates from this point of view. Our results are suggesting that there may in fact be a dynamic central peak in the Raman scattering pattern of Gadolinium Molybdate. This result might explain earlier difficulties in ascertaining the critical behavior of these crystals. If successful, our analysis should identify the low energy excitation with which the soft mode is interacting, the interaction itself giving rise to the central peak. Since the frequency of acoustic phonons coupling with the soft mode is predicted to follow the same law as the hard optical modes we intend to include triple pass Brillouin scattering in our experimental plan for the coming year. Progress: None

Recent Publications: (Delinquent)

SUPERCONDUCTIVITY

NR 319-055, University of California, Berkeley, "Josephson Effect Detectors of Microwave and Far Infrared Radiation", Paul L. Richards, (415) 642-3027, N00014-75-C-0496

Our long term goal under this contract is to develop receivers of millimeter and submillimeter waves, which are rugged and reliable and which perform important tasks better than any competing technology. During the early years of this contract experimental and theoretical investigations of Josephson Effect heterodyne mixers were carried out. More recently attention has been focused on devices which make use of the nonlinearity of the quasiparticle tunneling current in thin film superconductor-insulator-superconductor tunneling junctions. At the end of the last contract year, Pb-In-Au alloy SIS tunnel junctions made by R. E. Harris and F. L. Lloyd at the National Bureau of Standards has been used to make a 36 GHz heterodyne mixer. The properties of this mixer were extremely favorable. The single-sideband mixer noise temperature was too low to measure. An upper limit of 14K was set. A single-sideband conversion efficiency of 0.16 was measured which is about as large as could be expected from a classical mixer of this type. Evidence that classical theory was breaking down was observed. Progress: During the past year mixing experiments have been carried out in linear arrays of 100 Sn tunnel junctions and in Pb-Bi tunnel junctions. Both types of junctions were selected to have a sharp onset of tunneling current at the full superconducting energy gap voltage. Low-noise mixing has been observed in both structures with evidence for conversion gain. This gain is predicted by calculations of mixer performance using photon-assisted-tunneling theory. It is of highest importance for practical microwave receiver performance since it promises to reduce the importance of IF amplifier noise. In a parallel development, direct microwave detection was studied in Pb-In-Au alloy SIS tunnel junctions. The responsivity of this detector was quantum limited with a quantum efficiency of 0.5. The limiting noise was shot noise in the DC bias current. The NEP of this microwave photon detector was 3×10^{-16} W/$\sqrt{\text{Hz}}$.

Recent Publications:

1. E.E. Haller, M.R. Heuschen, and P.L. Richards, Appl. Phys. Letters 34, 495 (1979).

2. P.L. Richards, T.M. Shen, R.E. Harris, and F.L. Lloyd, Appl. Phys. Letters 34, 345 (1979).

NR 319-062, State University of New York, Stony Brook, "Superconducting Broadband Arrays", P.I.-Professor J. E. Lukens, (516) 246-6119, N00014-75-C-0769

The properties of tunable arrays of Josephson oscillators are being studied in the 1-18 GHz frequency range. Specific points of current investigation are: methods for obtaining in-phase, coherent oscillations in large arrays, and properties of several types of individual junctions which might be used in arrays. Progress: Studies of arrays have been extended to ten junction arrays. A technique for biasing the junctions has been developed and tested which produces a common dc voltage across all junctions although only one current source is used for the array. It has been demonstrated, thru injection locking the array, that the ten junction array generates one hundred times the power of a similar single junction into a load of the same high impedance. A method has been developed and tested to achieve self-phase-locking in a ten junction array using an rf feedback loop. The

self-locked array can be tuned thru a frequency range of 4 to 40 GHz. Lithographic and thin film techniques have been improved to permit the fabrication of the self-locked arrays, which require four levels of lithography.

Recent Publications:

1. "Fabrication of Microbridge Josephson Junctions Using Electron Beam Lithography", J.E. Lukens, R.D. Sandell and C. Varmazis, Future Trends In Superconductive Electronics (Charlottesville, 1978), AIP Conference Proceedings No. 44, Edited by B.S. Deaver, Jr., C. M. Falco, J. H. Harris and S. A. Wolf (AIP, New York, 1978), p. 298.

2. "Study of the Properties of Coherent Microbridges Coupled by External Shunts", R.D. Sandell, C. Varmazis, A.K. Jain and J.E. Lukens, Future Trends In Superconductive Electronics (Charlottesville, 1978), AIP Conference Proceedings No. 44, Edited by B.S. Deaver, Jr., et al. (AIP, New York, 1978), p. 327.

3. "Generation of Coherent Tunable Josephson Radiation at Microwave Frequencies with Narrowed Linewidth", C. Varmazis, R.D. Sandell, A.K. Jain, and J.E. Lukens, Appl. Phys. Lett. 33(4), 357 (1978).

4. "Flux Modulated Coherent Radiation from Arrays of Josephson Microbridges Coupled by Superconducting Loops", R.D. Sandell, C. Varmazis, A.K. Jain and J.E. Lukens, IEEE Trans. on Magn., Vol. MAG-15, No. 1, 462 (1979).

5. "Measurement of the Size Dependence of the Current Phase Relation in Microbridge Josephson Junctions", S.S. Pei, J.E. Lukens and R.D. Sandell, to be published in Appl. Phys. Lett., January 1980.

NR 319-072, The Aerospace Corporation, "Josephson Parametric Amplification", P.I.-A. H. Silver, (213) 648-5840, N00014-79-MP90006

Josephson junctions hold great promise for microwave and high speed digital signal processing. This program addresses the fabrication of Josephson junctions by other than vacuum deposition of thin film-oxide sandwiches and the parametric response of micro-SQUIDs and arrays. Current research centers on a demonstration of a gate-controlled Pb-InAs-Pb planar Josephson junction and on the design of a high power, low noise parametric amplifier using a microSQUID lattice array. During the coming year the techniques of high-field pulse platihg and etching will be investigated for several of the problem areas in micron-size oxide tunnel junctions: grain size in the base electrode, oxide formation, and overlay deposition. Investigations of the SQUID arrays will continue with increased emphasis on fabrication and measurement of the structures. Progress: During the last year a triangular lattice of dc SQUIDs was analyzed in an antisymmetric flux mode. This mode was shown to be stable, and the gain, bandwidth, impedance, and saturation power were derived. Investigation of the planar Pb/InAs structures at submicron separations revealed new problems in surface control and electroplating. An incompatability between controlled electroplating to produce ohmic contacts and the surface preparation developed earlier remains unresolved.

Recent Publications:

1. "The Surface Conductance of Argon-Ion-Bombarded P-Type InAs", M.F. Millea, A.H. Silver, and L.D. Flesner, Thin Solid Films 56, p. 253-266 (1979).

2. "Supercontacting Contacts to InAs", M.F. Millea, A.H. Silver, and L.D. Flesner, IEEE Trans. on Magnetics MAG-15, p. 435-438 (1979).

3. "Effect of Order Parameter Relaxation on Josephson Junction Transients", H. Suhl, J.P. Hurrell, A.H. Silver and Y. Song, Journal de Physique 39 Supplement, C6-550-551 (1978).

4. "SQUIDs - Past, Present, and Future", A.H. Silver, IEEE Trans. on Magnetics MAG-15, p. 268-275 (1975).

NR 319-080, National Bureau of Standards, Boulder, "Fundamental Limits of Superconducting Electronics", P.I.-Dr. D. G. McDonald (303) 499-1000, ext 4113, N00014-79-F-0047

The fundamental limits of superconducting devices as components in an integrated superconducting electronic technology are of primary interest in this program. An example project is to make electrical pulses with widths approaching the intrinsic response time of the superconducting state, $\sim$ 1 picosecond. Another project is to make a millimeter wave mixer with conversion loss and effective noise temperature approaching the theoretical minimum value. A third area of interest is to expand the scope of potential applications of the technology by developing a simple superconducting amplifier which could play the role of the transistor in conventional electronics. For this purpose we have investigated both equilibrium and nonequilibrium mechanisms. In support of these projects we have assembled a dedicated microcircuit fabrication laboratory. In FY80 the main effort will be studying the limiting properties of a SQUID based amplifier and a microwave-driven picosecond pulser. A commercial electron-beam lithography system has been ordered so that size limitations of basic devices can also be investigated in the future. Progress: During the past year an advance was made in the highest speed measurement ever made in an electronic circuit -- to 9 picoseconds (ref. 1). An increased understanding of nonequilibrium processes in controlled weak links was achieved. Initial versions of picosecond pulse producing circuits and SQUID amplifying circuits were designed and fabricated.

Recent Publications:

1. "A Superconducting Sampler for Josephson Logic Circuits", C.A. Hamilton, F.L. Lloyd, R.L. Peterson, and J.R. Andrews, Applied Physics Letters, Nov. 1979.

2. "Simple-Heating-Induced Josephson Effects in Quasiparticle-Injected Superconducting Weak Links," S. B. Kaplan, submitted to Journal of Applied Physics.

3. "Acoustic Matching of Superconducting Films to Substrates," S.B. Kaplan, Journal of Low Temperature Physics 37, 343 (1979).

NR 319-094, Massachusetts Institute of Technology, "A New Approach to the Synthesis of Metastable A15 Superconductors with High Transition Temperatures", P.I.-Robert M. Rose, (617) 253-3230, N00014-76-C-0297

The goal of this project is to produce Nb_3Si (or a similar unstable compound) in the A15 crystal structure by ion implantation in A15 substrate with controlled composition profiles, and subsequent epitaxial regrowth of the implanted layer.

The rationale is simply that very high transition temperatures for superconductivity may be possible with Nb_3Si in the A15 structure; and also that the approach can be used to synthesize other unstable materials. Progress: Previously, we showed that this approach would, as hoped, create A15 layers of silicon-rich compound. To raise the transition temperatures we have, in the past year, developed new substrates with much better homogeneity and, through a collaborative arrangement, used the much higher silicon fluxes available at the Argonne heavy ion accelerator. We are just beginning to explore the resulting materials; preliminary results indicate the development of a broad resistive transition in the 18-30°K range and a possible structural transition at ca. 40° K. We hope to confirm and clarify these results in the near future.

Recent Publications:

1. "On the Synthesis of A-15 "Nb_3Si" by Ion Implantation", Mireille Treuil Clapp and R.M. Rose, Appl. Phys. Lett. 33(2), pp. 205-207 (1978).

2. "On the Superconducting Transition Temperature of A-15 "Nb_3Si" Synthesized by Ion Implantation", Mireille Treuil Clapp and R.M. Rose, IEEE Transaction on Magnetics, Vol. MAG-15, No. 1, January (1979).

3. "On the Synthesis of Metastable A-15 "Nb_3Si" by Ion Implantation and on its Superconducting Transition Temperature", Mireille Treuil Clapp and R.M. Rose, accepted for publication in J. Appl. Phys. (1979).

NR 319-096, Cornell University, "Superconducting Devices", P.I.-Dr. R.A. Buhrman (607) 256-3732, N00014-76-C-0526

Submicron Josephson junctions of various thin film types are being fabricated and studied. The program objectives are to develop more reliable, higher performance junctions for device applications and to improve the understanding of the different types of junctions. Progress: An extensive study of sub-micron thin film superconductor-normal metal-superconductor junctions has been completed. The limiting intrinsic response time of such SNS junctions has been determined. This response time is in good accord with straightforward Ginzberg-Landau theory predictions. Very large microwave enhancements of the critical current of these junctions has also been observed. This enhancement results from the spatial averaging of the electron distribution within the normal metal and is not due to a microwave enhancement of an energy gap-the usually accepted mechanism for critical current enhancement. In a different project a new technique for producing $Nb-Nb_2O_5-Pb$ tunnel junctions has been developed which yields junctions in excess of 10^4 amps/cm^2.

Recent Publications:

1. "Planar SNS Microbridges", J.M. Warlaumont and R.A. Buhrman, IEEE Transaction on Magnetics MAG-15, 570, (1979).

2. "Response Times and Low Voltage Behavior of SNS Microbridges", J.M. Warlaumont, J.C. Brown and R.A. Buhrman, Applied Phys. Letts. 34, 415-418 (1979).

3. "Microwave-Enhanced Proximity Effect in Superconductor-Normal Metal-Superconductor Microjunctions", J.M. Warlaumont, J.C. Brown, T. Foxe and R.A. Buhrman, Phys. Rev. Lett. 43, 169-172 (1979).

NR 319-105, Stanford University, "Superconducting Magnetometer", P.I.- Dr. R. P. Giffard, N00014-76-C-0848

The effective use of Josephson effect devices in Superconducting Electronics depends on the degree to which they can be reliably characterized. Accurate measurements of device behavior can also lead to advances in theoretical understanding. The objectives of the present research are to obtain accurate equivalent circuits for Josephson junctions and coupling structures, and to improve the understanding of sensitivity limitations in practical SQUID devices. Progress: The significance of SQUID amplifier input noise in defining optimum operating conditions and ultimate sensitivities has been investigated. The input noise of a typical r.f. SQUID system has been measured, allowing a noise temperature to be assigned to the device. The equivalent circuit of typical point contact weak links has been measured at 10 GHz in a resonant coupling structure.

Recent Publications:

1. "Low Frequency Impedance and Noise Properties of an r.f. Biased Resistive SQUID", R.P. Giffard, P.F. Michelson and R.J. Soulen, Jr., IEEE Trans. Mag. MAG 15, 276, (1979).

2. "High Sensitivity Microwave SQUID", J.N. Hollenhorst and R.P. Giffard, IEEE Trans. Mag MAG 15, 474, (1979).

3. "Performance of a Resonant Input SQUID Amplifier System", M.B. Simmonds, W.A. Fertig and R.P. Giffard, IEEE Trans. Mag. MAG 15, 478, (1979).

4. "Input Noise in the Hysteretic r.f. SQUID: Theory and Experiment", J.N. Hollenhorst and R.P. Giffard, J. Appl. Phys. (in press).

5. "Optimization of d.c. SQUID Voltmeter and Magnetometer Circuits", J. Clarke, C.D. Tesche and R.P. Giffard, J. Low Temp. Phys. (in Press).

NR 319-116, Harvard University, "Fundamental Processes in Superconducting Weak Links", P.I. - Professors M. Tinkham (617) 495-3735, and W.J. Skocpol, (617) 495-3297, N00014-77-C-0085

By studying nonequilibrium effects in superconducting weak links of various types--point contact, variable-thickness bridges, high-current-density tunnel junctions, and phase-slip centers in long bridges and filaments--a deeper understanding of how such devices work is sought so that their fundamental limitations can be understood and circumvented as much as possible. One current goal is to understand better the nonequilibrium electronic coupling (via charge imbalance waves) between nearby weak links in an array or between phase-slip centers in a long filament. Another is to understand better the I-V curves of point contacts, where features at the gap voltage have been shown to correlate with far-infrared Josephson effect response, and features at phonon energies give information about the fundamental electron-phonon coupling. Measurements of the low-frequency noise properties of these devices are being made, since excess noise can greatly degrade their performance as detectors of electromagnetic radiation. Progress: The superior performance of tin variable thickness bridges, as judged by the voltage to which x-band Josephson steps could be seen, has been demonstrated and

quantitatively explained in terms of a heating theory. An extensive account of the measured performance of Nb point contacts in the far-infrared frequency domain has been published. The magnetic field dependence of the charge-imbalance relaxation times associated with phase-slip centers in superconducting bridges has also been measured and a theory of the charge-imbalance waves generated by such centers has been developed.

Recent Publications:

1. "Junctions-Types, Properties, and Limitations", M. Tinkham, invited paper, Charlottesville Conf. on Future Trends in Superconductive Electronics, AIP Conf. Proc. 44 (ed. Deaver, et al), 269-79 (1978).

2. "High-Frequency Properties of Microbridge and Point Contact Josephson Junctions", W.J. Skocpol, Charlottesville Conf. on Future Trends in Superconductive Electronics, AIP Conf. Proc. 44 (ed. Deaver, et al), 335-9 (1978).

3. "Characterization of Niobium Point Contacts Showing Josephson Effects in the Far Infrared", D.A. Weitz, W.J. Skocpol, and M. Tinkham, J. Appl. Phys. 49, 4873-80 (1978).

4. "Properties of Josephson Point-Contact Far-Infrared Detectors", D.A. Weitz, W.J. Skocpol, and M. Tinkham, Infrared Physics 18, 647-56 (1979).

5. "Far-Infrared Frequency Dependence of the ac Josephson Effect in Niobium Point Contacts", D.A. Weitz, W.J. Skocpol, and M. Tinkham, Phys. Rev. B18, 3282-3292 (1978).

6. "Magnetic Field Dependence of Relaxation Times in Nonequilibrium Superconductors", A.M. Kadin, W.J. Skocpol, and M. Tinkham, J. Low Temp. Phys. 33, 481-503 (1978).

7. "Measurement of Potential Differences in Nonequilibrium Superconductors", W.J. Skocpol, A.M. Kadin, and M. Tinkham, Invited Paper, LT15, Grenoble, J. Physique 39, C6:1421-1426 (1978).

8. "Microwave Response of Superconducting Variable-Thickness Microbridges", M. Octavio and W.J. Skocpol, J. Appl. Phys. 50, 3505-3509 (1979).

9. "The Interaction of Phase-Slip Centers in Superconducting Filaments", M. Tinkham, J. Low Temp. Phys. 35, 147-151 (1979).

10. "Non-Equilibrium Superconductivity", M. Tinkham, Review article in "Festkörperprobleme/Advances in Solid State Physics", Vol. XIX, p. 363-385, J. Treusch (ed.), Vieweg, Braunschweig (1979).

NR 319-120, Massachusetts Institute of Technology, "Conducting Polymers", P.I.-Professor S.D. Senturia, N00014-77-C-0361

The conductivity properties of gas-sensitive polymer films are studied using conductivity-adsorption isotherms both with conventional interdigitated electrode structures and with charge-flow transistor, a new MOS device that resembles a conventional MOSFET, but with a portion of the gate metal replaced by the polymer film study. Recent work has focused on the moisture-sensitive polymer poly

(p-aminophenylacetylene), abbreviated PAPA. In addition, work on novel sensing circuits that employ charge-flow transistors has continued. Progress: Studies of the conductivity-adsorption isotherms of the thin films of PAPA on interdigitated electrode structures have revealed that there are two activation energies of conduction above 30% RH, a 0.35 eV process below 40°C, and a 1.1 eV process above 40°C. Both processes scale together with relative humidity, suggesting that both are due to mobile ions produced in the polymer by the disassociation of adsorbed water. The .35 eV process is identified with the water molecules themselves, while the 1.1 eV process is identified with proton conductivity along the polymer chains. Below 30% RH, the conductivity of the films becomes non-Ohmic. In dry environments, the current-voltage characteristic exhibits a square law dependence, a behavior usually associated with space-charge-limited currents in the vicinity of the electrodes. Charge-flow transistors incorporating PAPA have also been studied, both as discrete devices, and in new oscillator circuits in which the turn-on delay of the CFT is what determines the frequency of oscillation.

Recent Publications:

1. "A Charge-Flow Transistor Oscillator Circuit", Stephen D. Senturia and Michael T. Fertsch, J. Solid-State Circuits, SC-14, 753-757 (1979).

NR 319-121, Stanford University, "Superconducting Tunneling and Tunneling Applications in High-T_c A15 Superconductors", P.I.-M. R. Beasley (415) 497-1196 N00014-77-C-0439

The objective of this program is to study the fabrication, properties and device potential of superconducting tunnel junctions incorporating high transition temperature superconductors. Such a study is of interest not only because of the possible Josephson and other superconducting device applications of such junctions but also because of the important detailed, quantitative information tunneling studies provide about the superconducting state and in particular the electron-phonon interaction responsible for superconductivity. The present effort is on understanding the nature of tunneling barriers present on our successful junctions on Nb_3Sn and V_3Si and extending these techniques to other A15 superconductors. Application of our Nb_3Sn junctions to determination of the electron-phonon interaction spectral function $\alpha 2_F(\omega)$ are also continuing. Progress: Application of recent detailed models of the influence of proximity effects on superconducting tunneling have been applied to our Nb_3Sn tunneling data. The results indicate that a slight influence of the proximity of an inferior superconducting layer on the surface of our high-T_c base electrodes is present. Analysis of the data taking such effects into account have led to an improved determination of $\alpha 2_F(\omega)$. Analysis of a wide variety of junctions incorporating our oxidized amorphous Si barriers has demonstrated their wide applicability with transition-metal-based materials and led to a successful model for their behavior.

Recent Publications:

1. "The Tunneling Density of States of Superconductive Nb-Sn", by M.R. Beasley, and J.M. Rowell, Proceedings of the 15th International Conference on Low Temperature Physics, LT-15 Grenoble, France, J. de Phys. 39, C6-1390 (1978).

2. "Josephson Properties of Nb_3Sn/Pb Tunnel Junctions", R.E. Howard, D.A. Rudman, and M.R. Beasley, Appl. Phys. Lett. 33, 671 (1978).

3. "Energy Gaps of the A15 Superconductors Nb_3Sn, V_3Si and Nb_3Ge Measured by Tunneling", D.F. Moore, R.B. Zubeck, J.M. Rowell and M.R. Beasley, to appear in Phys. Rev. B.

4. "Fabrication and Barrier Diagnostics of Superconductive Tunnel Junctions On Nb-Sn and V-Si", D.A. Rudman, R.E. Howard, D.F. Moore, R.B. Zubeck, and M.R. Beasley, IEEE Trans. Mag. MAG-15, 582 (1979).

NR 319-123, University of California, Berkeley, "Analog-to-Digital Data Processing", P.I.-Professor T. Van Duzer, (415) 642-3306, N00014-77-C-0419

The objective of this research is to evaluate the potentiality of Josephson digital circuits for use in high-speed analog-to-digital signal conversion. Progress: We have designed an architecture for a 4-bit, 5 GHz A/D converter which involves parallel 4-bit Gray code digitalization in the input comparator stage and a subsequent recoding to ordinary binary for the output. The work has focused on developing the fabrication technology and answering some of the basic questions regarding circuit performance by simulation. The fabrication technology emp oyed is the lead-alloy system reported by IBM but we have also been studying new alloys as possible improvements on the lead-gold-indium system. We have studied by simulation the switching of a series array of ten junctions with interconnecting transmission line sections to look for possible problems with high frequency components for short rise times. This circuit is planned for interfacing to the outside semiconductor circuits. We have also studied the switching of single junctions and interferometers using the minimum possible pulse lengths. The minimum pulse length has been computed using simulation and approximate analytic expressions have been found which reveal functional dependences on the circuit parameters. In a third study, an analysis has been made of a phenomenon known of as "punchthrough". The logic circuits employing Josephson junctions can be operated with a bipolar clocked gate current supply. The circuits considered are of the latching type so they must be reset after each clock period and this happens as the clocked gate current changes polarity. We have been calculating the probability that the gate will not reset to zero as the supply passes through zero in order to find how the supply switching time and device parameters must be adjusted to minimize the probability of this kind of logic failure. In the coming year the simulation work will continue, with emphasis on larger circuits. The first such effort will be directed toward the input comparator circuits. We will also start fabricating and testing some of the devices studied by simulation.

Recent Publications:

1. "Josephson Digital Devices and Circuits", T. Van Duzer, IEEE Trans. on Microwave Theory and Techniques, To be published May 1980.

NR 319-12[illegible], University of Virginia, "Superconductive Electronics", P.I.-Dr. Pascom C. Deaver, Jr. (804) 924-3781, Dr. Robert J. Mattauch (804) 924-3564, N00014-[illegible]-C-0440

The objectives of this research are 1) to fabricate and test Josephson mixers for use at frequencies greater than 100 GHz and 2) to fabricate and characterize micro-tunnel junctions and niobium variable thickness microbridges, particularly ones on semiconductor substrates with possible interaction between the supercurrent and the semiconductor. Junctions and microbridges are being fabricated and characterized by measurements of I-V and dV/dI as functions of temperature, magnetic field and incident microwave power, and operated as mixers at frequencies ∿100 GHz. An on line computer/controller is used to record and manipulate the data for systematic study of the features of the data. Progress: Micro-tunnel junctions are being fabricated by using chemical vapor deposition to coat a Nb film with a 1 μm-thick layer of SiO_2, using photolithography and plasma etching to form a straight-sided hole 2 μm diameter through the oxide, depositing Si as a tunnel barrier and a second Nb film as the top electrode. The fabrication steps have been developed and the first complete junctions are being fabricated for testing. Niobium variable thickness bridges on quartz, Si and GaAs substrates have been characterized and tested as mixers at 85 GHz. Both Josephson and bolometric mixing are observed. Heating effects that limit Josephson mixing have been studied extensively. At high current bias the I-V curves exhibit a complicated structure that varies systematically with temperature and microwave power. Some of these features have been identified as synchronized multiple flux flow.

Recent Publications:

1. "Heating and Flux Flow in Niobium Variable Thickness Bridges", Li-Kong Wang, Dae-Jin Hyun and Bascom S. Deaver, Jr., Journal of Applied Physics 49, 5602-5609 (1978).

2. "The Microtunnel Josephson Junction", John Upshur and Robert J. Mattauch, Proceedings of the IEEE Region 3 Conference, Southeastcon '79, 79 CH 1432-4 (1979).

3. "Current-Voltage Characteristics of Superconducting Weak Links in the High Current Regime", Christopher Galfo, September 1979. Technical Report.

NR 319-130, University of California, San Diego, "An Investigation of Superconductivity in Se iconductors", P.I.-A. H. Silver (213) 648-5840 and H. Suhl (714) 452-4748, L. D. Flesner (714) 452-4079, N00014-78-C-0029

The program is an exploration of interactions between superconductors and special semiconductors which in combination may evolve new Josephson and electron tunneling devices. A specific goal is to achieve Josephson coupling mediated by a semiconductor surface and controllable by an electrically isolated gate electrode. Because of its unique surface electronic properties, p-InAs is the principal semiconductor material being investigated. Two approaches are being pursued: (1) fabrication of superconducting contacts with submicron spacing on the semiconductor surface; and (2) study of evaporated superconducting granular films on the semiconductor. Progress: Results from devices with 1 μm contact spacing suggest a superconducting proximity region in the p-InAs surface of ∿0.1 μm. Work is in progress to produce devices with this spacing. Results from granular structures (grain spacing ∿0.01 μm) of In on p-InAs indicate Josephson coupling between grains. Work is in progress to determine whether modulating the substrate conductance can also modulate the coupling strength.

Recent Publications:

1. "Superconducting Contacts to p-InAs", M.F. Millea, A.H. Silver and L.D. Flesner, IEEE Trans. on Magn., MAG-15, No. 1, 435-438 (1979).

2. "The Surface Conductance of Argon-Ion-Bombarded p-Type InAs", M.F. Millea, A.H. Silver, and L.D. Flesner, Thin Solid Films, 56, 253-266 (1979).

NR 319-131, IBM Research Laboratory, San Jose, "Electrical Properties of Anisotropic Solids", P.I.-G. B. Street and R. L. Greene, (408) 256-3044, 256-1268, N00014-76-C-0658

The object of this research is to understand at a fundamental level the physical and chemical properties of anisotropic solids which exhibit novel electrical or magnetic properties. In the past we have studied the organic charge transfer salts, e.g., TTF-TCNQ, the polymer $(SN)_x$ and its halogen derivatives and more recently $(CH)_x$ and doped $(CH)_x$. The basic understanding of the chemistry and physics of $(CH)_x$ which we have achieved has lead to the development of new semiconducting polymers of possible technological importance. Progress: We have made considerable progress in understanding both the mechanism of doping and the final structure of doped $(CH)_x$. Using FTIR techniques we have been able to account for the FTIR spectra of doped $(CH)_x$ in terms of bond weakened C=C and C-C modes consistent with the idea of electron transfer from the CH_x to the dopant. Using EXAFS and FTIR it has been demonstrated that for AsF_5 doping the final form of the dopant is AsF_6^-. The reduced form of the dopant has been shown to intercalate between the planes of the $(CH)_x$ chains analogous to the structure of brominated $(SN)_x$. We found that undoped trans-$(CH)_x$ forms a well defined Schottky Barrier with several metals. From this we measured the photovoltaic effect in $(CH)_x$ and determined its band gap to be 1.5 eV. This agrees well with our previous band structure calculations. Work is in progress to evaluate $(CH)_x$ as a possible solar cell material. We found from proton NMR experiments on $(CH)_x$ evidence for a highly one-dimensional mobile spin defect. This defect appears to be fundamental to many conjugated polymer systems and may play an important role in the doping and transport properties. Finally, we prepared several new polymers, including polypyrrole. This polymer, like $(CH)_x$, is metallic but it is non-fibrous and has greater stability and electrical uniformity. Unlike $(CH)_x$ it does not require external doping with toxic materials to make it metallic.

Recent Publications:

1. "Chemistry and Physics of Polythiazyl $(SN)_x$ and the Polythiazyl Halides", G.B. Street and W.D. Gill, Molecular Metals, p. 301, Plenum (1979).

2. "The Mechanism of Arsenic Pentafluoride Doping of Polyacetylene", T.C. Clarke, R.H. Geiss, W.D. Gill, P.M. Grant, H. Morawitz and G.B. Street, Syn. Metals, 1, 21 (1979).

3. "Vibronic Intensity Enhancement in the IR Spectra of Heavily Doped $(CH)_x$ and $(CD)_x$," J.F. Rabolt, T.C. Clarke, G.B. Street, J. Chem. Physics, Dec. 1979.

4. "Polypyrrole, A Stable Synthetic Metallic Polymer", K. Kanazawa, A.F. Diaz, R.H. Geiss, W.D. Gill, J.F. Kwak, J.A. Logan, J.F. Rabolt and G.B. Street, J.C.S. Chem. Commun. 854, (1979).

5. "Transport Properties of Doped Polyacetylene", J.F. Kwak, T.C. Clarke, R.L. Greene and G.B. Street, Solid State Commun. 31, 355 (1979).

NR 319-136, Stanford University, "Miniature Cryogenic Refrigerator", P.I. - W. A. Little, (415) 497-4233, N00014-78-C-0514

The objective of this research is to design and construct an extremely small cryogenic refrigerator suitable for integration into an ultrasensitive sensor system for Naval applications. Progress: Almost all parts of a J-T refrigerator designed to produce 100 milliwatts of refrigeration at 77 K on a 2" Si-wafer using N2 have been constructed. Using photolithographic techniques it has been possible to construct the entire refrigerator--gas manifold, particulate filter, heat exchanger, Joule-Thompson expansion nozzle and liquid collector--in one step. All refrigerator components have been pressure tested to 1000 psi without failure. Successful operation of a refrigerator using CO_2 has been demonstrated.

Recent Publications:

1. W. A. Little, "Design and Construction of Microminiature Cryogenic Refrigerators", in Future Trends in Superconductive Electronics, ed. B. S. Deaver, AIP Conference Proceedings 44, 421 (1978).

NR 319-137, University of Rochester, "A New Class of Ultra-Stable Clocks and Frequency Sources", P.I.-Professor David H. Douglass (716) 275-4573, N00014-78-C-0578

The fundamental limits on the frequency stability of a mechanical resonator has never been reached. Recent studies on high Q materials such as sapphire, silicon and certain aluminum alloys indicate that mechanical oscillators made of these materials could have a frequency stability considerably better than that achieved by the hydrogen maser and the superconducting cavity stabilized oscillator. The general approach is to cool these crystals and resonators to low temperatures where the high quality factors are achieved. At these temperatures, there is essentially no temperature dependence of the frequency. Progress: October 1, 1978 to September 30, 1979. A high Q (10^7) aluminum cylinder of 0.6 kg mass and frequency 12 kHz was made into a resonator and cooled. Two piezocermanic elements were bonded to each side of the barrel of the cylinder. One was used to sense the vibrations and the other was used in a feed-back loop to drive the oscillator. The frequency stability was found to be at least as good as our best laboratory frequency source which is a Hewlett Packard crystal oscillator. We have acquired a much more accurate quartz frequency source from Austron and will proceed to repeat the experiment with this oscillator.

Recent Publications:

1. "Experiments on High Q Mechanical Oscillators", D.H. Douglass and R.Q. Gram, Submitted to Bull. of Am. Physical Society.

2. D.F. McGuigan and D.H. Douglass, Proceedings of 31st Annual Symposium on Frequency Control, 1-3 June, 1977, Published by Electronics Industries Association.

NR 319-138, Cornell University, "Dynamical Properties of Superconductive Devices

and Materials", P.I.-Professor Vinay Ambegaokar, (607) 256-5163, N00014-78-C-0666

The general aim of this work is to use microscopic theory to study time-dependent or steady-state nonequilibrium phenomena in weak-links, films, filaments, tunnel-junctions, and other superconducting systems. Recent projects include: (1) the derivation of dynamical equations for the order parameter and the electric potential in a short mean-free path superconductor near the critical temperature, and the study of the collective mode spectrum of the system in the presence of supercurrents (1); (2) a study of nonequilibrium steady states in a superconductor in which electrons are injected via a tunnel-junction and the prediction that two stable values of the energy gap may co-exist in some situations (2,3). Currently, work is proceeding on understanding the phase locking of nearby Josephson junctions. Progress: In the new project mentioned at the end of the last paragraph, we have understood how the phase of a single Josephson junction locks to the frequency of an impressed current. We are now considering the case of two junctions being driven by constant currents and communicating by a linking impedance. Assuming small coupling, we can calculate the limits of applied currents for which the internal frequencies of the two junctions, i.e., the average voltages across each, remain equal. Perturbation theory in the small coupling is being used to understand the nonlinear equations describing the dynamics. The effect of thermal noise on this locking is also being investigated.

Recent Publications:

1. "Collective Modes and Nonequilibrium Effects in Current-Carrying Superconductors", by Gerd Schön and Vinay Ambegaokar, Phys. Rev. B19, 3515 (1979).

2. "Nonequilibrium Superconducting States with Two Coexisting Energy Gaps", by Gerd Schön and Andre-M. Tremblay, Phys. Rev. Lett. 42, 1086 (1979).

3. "Effect of Nonequilibrium Phonons on Superconducting States with Two Coexisting Energy Gaps", by Andre-M. Tremblay and Gerd Schön, to appear in the proceedings of the conference on "Inhomogeneous Superconductors" held at Berkeley Springs, WV, November 1-3, 1979 (AIP Conference Proceedings).

NB 319-139, University of Minnesota, "Tunneling in Magnetic Superconducting Systems", P.I.- Allen M. Goldman, (612) 373-5480, Louis E. Toth, (612) 373-4864, N00014-78-C-0619

Research into the nature of the interaction between magnetism and superconductivity is important in establishing a fundamental understanding of both phenomena. The rare earth ternary compounds such as the Chevrel phase compounds and the rare earth rhodium borides high-light the interrelation between magnetic ordering and superconductivity. Superconductivity as well as being quenched by the onset of magnetic ordering can, under certain circumstances, coexist with it. The competition between magnetic ordering and superconductivity is being studied in rare-earth ternary compounds prepared in the form of films using electron tunneling as the primary tool. Thus thin films of the rare earth rhodium borides and the rare earth Chevrel phase compounds are being made and characterized. Tunneling junctions will then be fabricated with these ternary compounds. Then, using tunneling, it should be possible to study the temperature dependence of the energy gap, the coupling between the magnetic ions and the superconducting electrons and the space and time variation of the superconducting order parameter. The rare earth Chevrel

phase compounds are potentially of great technological importance because of their high critical magnetic fields. The successful fabrication of thin films and in turn the formation of films on flexible substrates, which is also planned, may be important steps towards realizing the potential of these materials.
Progress: Research results in the past year include the successful fabrication of $Er(RhB)_4$ films which exhibit reentrant behavior and the measurement of the parallel and perpendicular critical magnetic fields of these films. A unique result is the observation that in $Er(RhB)_4$ films the perpendicular critical field is larger than the parallel. An apparatus for the fabrication of Chevrel phase films using a molecular beam technique has also been developed.

Recent Publications:

1. "Sputter Deposition of Thin Films of Superconducting $Er(RhB)_4$", G.L. Christner, B. Bradford, L.E. Toth, R. Cantor, E.D. Dahlberg, A.M. Goldman, and C.Y. Huang, J. Appl. Phys., 50, 5820 (1979).

2. "Critical Magnetic Fields of Superconducting Thin Films of $Er(RhB)_4$", R.H. Cantor, E.D. Dahlberg, A.M. Goldman, L.E. Toth, and G.L. Christner, submitted to Solid State Commun.

NR 319-141, Naval Research Laboratory, "Cryocoolers", P.I.-R. C. Collins, (202) 767-2793, N0001480WR00011

Stirling-type coolers have been used extensively over temperature ranges down to 20°K. One of the barriers to lower temperatures is the vanishing small heat capacity of all of the materials normally used in the thermal regenerator - a necessary part of the cooler. Unlike other substances, gaseous helium does not suffer a similar decrease in specific heat at very low temperatures. The proposed approach is to subject the working fluid (helium) to indirect contact with trapped helium under pressure at the cold end of a conventional regenerator.
Progress: New

NR 319-145, National Bureau of Standards/Boulder, "International Cryogenic Materials Conference Board, "3rd International Cryogenic Materials Conference", P.I.-Dr. Alan F. Clark, (303) 499-1000 x3253, N00014-79-G-0054

The purpose of the grant is to provide partial support for the 3rd International Cryogenic Materials Conference (ICMC) which was conducted on 21-24 August 1979, at the University of Wisconsin, Madison, Wisconsin. The ICMC provides a forum for the presentation and discussion of low temperature materials research. The grant assists in the ability of the conference to draw excellent invited speakers.
Progress: The conference was held as scheduled, jointly with the Cryogenic Engineering Conference. More than 500 attended and presented about 200 papers (½ were ICMC) and the conference was generally acclaimed to be highly beneficial. Papers were submitted and the proceedings are in preparation.

Recent Publications:

1. The conference proceedings will be published as Advances in Cryogenic Engineering, Volume 26, edited by A. F. Clark and R. P. Reed, Plenum Publishing, New York (1980). Prior Conferences were Volumes 22 and 24.

NR 319-148, Naval Ocean Systems Center, "Transition Times of Nonhysteretic SQUIDs Constructed of S-N-S Microbridges", P.I.-Dr. Edward Jelks, Mr. George Kerber, Dr. Howard Wilcox, N00014-79-WR-90055

The purpose of this work is to study the dynamic behavior of nonhysteretic SQUIDs constructed of Superconducting-Normal-Superconducting microbridges. In particular, we will focus our effort on two-junction interferometers with junctions having vanadium banks and Au/Ti bridges, and we will measure the time required for these devices to change from the zero voltage state to the voltage state. Progress: (1 Aug 79 to 1 Oct 79) A number of V-Au/Ti-V microbridges on silicon with nominal bridge dimensions of 0.03μm(t)X0.2μm(w)X0.2μm(l) have been batch-fabricated using shadow depositions and optical lithography. The normal state resistances of these devices are about one to two ohms. A sample holder and cable assembly capable of transmitting pulses with 25 picosecond rise-times into and out of our cryostat is being constructed.

Recent Publications:

1. "A Simple Method for Fabricating Lines of 0.15-μ Width Using Optical Lithography", E.C. Jelks, G.L. Kerber, and H.A. Wilcox, Appl. Phys. Lett., 34 (1), 28-30 (1979).

NR 319-149, Cornell University, "Surveillance and Communication: Submicron Devices for Surveillance Systems", P.I.-Robert C. Richardson, (607) 256-6423, N00014-79-C-0708

The purpose of the project is to gain an understanding of how the fundamental properties of materials change when confined in small dimensions at low temperatures. Current work includes NMR studies of small insulating particles, initially 2000 Å diameter fluorocarbon sphere, and the development of a photolithographic method of producing large arrays of nearly identical metallic cubes with widths of less than 1 micron. Progress: New

NR 319-150, Instituto Venezolano de Investigaciones Cientificas, "Collaborative Project on the Superconducting and Normal Properties of Some Weak Link Geometries", P.I.-Dr. Miguel Octavio, TLF. 681 1188, Ext 449, N00014-79-G-0066

The fundamental properties of various superconducting weak links are being studied, as well as normal state processes which can be observed with them. Techniques are being developed for oxidizing tin and indium films in order to obtain high resistance, well-cooled variable-thickness microbridges and study their response to microwave and far-infrared radiation. Very short (lenght < 1000 Å) microbridges are also being studied. These bridges made of tin and lead initially, are fabricated by producing a discharge between two films separated by an insulating film. They will be used to study their equilibrium and nonequilibrium properties, their microwave response, and their electron-phonon interaction spectrum when the bridges are not in the superconducting state. Dielectric discharge bridges of higher T_c materials will be fabricated in order to compare their properties to other types of Josephson weak-links. Progress: New

NR SRO-006, University of California, San Diego, CA, "Membrane Receptors: Physics and Chemistry", P.I. - Professor Mauricio Montal, (714) 452-2483 N00014-79-C-0748

The molecular basis for the activity of membrane receptor proteins is one of the most challenging questions in membrane biology. The problem is approached by incorporating receptor proteins in model membrane systems which permit the use of many techniques that are otherwise inaccessible in intact cells. The following receptor proteins will be studied:

1. Reaction Centers of photosynthetic bacteria which perform the primary photochemical reactions of photosynthesis.

2. Acetylcholine receptor which is responsible for the transduction of ligand binding into a conductance increase at postsynaptic membranes.

3. Isolated receptor polypeptides which are involved in bacterial chemoreception and motility.

4. The Phosphate Transporter of cultured fibroblasts which is involved in coupled transport across membranes.

Simultaneous in vivo studies of receptor action will be performed: in neuro-muscular synapses by optical and electrical recordings to evaluate the existence of electrically silent "receptor states"; in cultured sympathetic nerve-like cells to assess the role of membrane composition in nerve function; in embrionic amphibian spinal neurons developing in culture to define the temporal differentiation of excitability. This multidisciplinary approach should provide insights into the molecular basis of energy transduction, signal coding, cellular recognition and development.

Progress: New

PHYSICAL ELECTRONICS

NR 372-003, Brown University, "Experimental and Theoretical Investigations of the Transport Properties of Semiconducting Surface Inversion Layers", P. I. - Dr. Phillip J. Stiles, N00014-76-C-0894

In recent years the study of the quasi-two-dimensional electron gas of a semiconducting surface space charge layer has gained increasing importance as a means of investigating the interactions of charged carriers with one another. A thorough understanding of the properties of such space charge layers is essential for successful construction of a class of advanced technology, surface active, solid state devices such as high speed computer memories and microwave amplifiers. The intent of this research program is to study, by comparison of experiment with theoretical analysis, the charge transport properties of inversion layers induced on various semiconductor surfaces. Until recently experimental studies have been limited to inversions induced at silicon-silicon dioxide interfaces. Due to field discontinuities at the surfaces of most semiconductors, and the difficulty in neutralizing the sources of such discontinuities, conducting inversion layers are not readily formed on materials other than silicon.

One aspect of the experimental program has been development of two techniques for forming native oxide layers, for surface passivation and electrical insulation, on semiconductors other than silicon.

Theoretical studies of subband structure, valley splitting, and electron-optical phonon interactions in germanium and in compound semiconductors are being carried out. Progress: The plasma oxidation technique, applied to various III-V series semiconductors, has been used to demonstrate that insulating oxide can be formed on GaAs, InAs, InSb and InP. Detailed studies of GaAs-oxide interfaces, by the Zerbst transient capacitance technique, indicate that sufficient passivation has been achieved of p-GaAs surfaces to permit inversion layer formation. Using this native oxide, MOSFET structures are currently being prepared to GaAs to provide the appropriate configuration for transport studies. The use of high pressure ($\geq$ 2000 psi) in conjunction with moderate temperature ($\sim$500°C) has been used on p-type germanium to form passivating oxides. Layers formed by this technique appear to be stable, reproducible, and of reasonably high dielectric constant. Germanium inversion layers are of interest for comparison with existing information on silicon because of certain similarities (and difference) in the directional properties of the constant energy surface between the two. The effect of electron-optical phonon coupling on the subband structure and optical absorption of inversion layers on compound semiconductors has been started. In the coming fiscal year, p-type GaAs MOSFET structures will be used to create pseudo-two-dimensional electron gases for study at low temperatures and high magnetic fields. Similar devices will be constructed on germanium after the quality and character of the Ge/GeO_x interface is established. Because of increased stability expected for nitride-based insulators, plasma and high pressure techniques will also be used to investigate the formation of nitrides on Ge and GaAs. Optical properties of inversion layers on compound semiconductors will continue to be investigated. In particular, effects associated with optical-phonon-electron interaction will be emphasized. The subband structure and valley degeneracy on different germanium surfaces will also be studied.

Recent Publications:

1. "Measurements of Minority Carrier Lifetime in GaAs Using the Transient Response of MOS Capacitors", V. Vitale, E.E. Crisman, J.J. Loferski and B. Roessler, Appl. Phys. Lett. 34 (1) 1 January 1979.

2. "Effect of the Electron-Phonon Interaction on the Subband Structure of Inversion Layers in Compound Semiconductors", G. Kawamoto, R. Kalia, and J.J. Quinn, Proc. Yamada Conf. on Two-Dimensional Systems, Lake Yamanaka, Japan (1979), pg. 728.

3. "Stress and Temperature Dependence of Subband Structure in Silicon Inversion Layers", S. Das Sarma, R. Kalia, M. Nakayama, and J.J. Quinn, Phys. Rev. B 19, 6397 (1979).

NR 372-010, Rensselaer Polytechnic Institute, "Semiconductor Surface and Semiconductor-electrolyte Interface Study Using Acoustic Surface Wave", P.I. - Dr. Pankaj Das, N00014-75-C-0772, (518) 270-6485

Surface acoustic wave (SAW) techniques are being developed for nondestructive evaluation of semiconductor surfaces and semiconductor-electrolyte interfaces, and for optical signal processing. The electric field propagating with a SAW on a piezoelectric substrate interacts with the free carriers in a semiconductor placed near the substrate. The effects of the interaction are monitored while the semiconductor is subjected to such external influences as bias voltages, illumination, and controlled temperature variations. Results from these experiments are analyzed to yield useful semiconductor parameters such as conductivity, majority carrier type, surface state distribution, capture cross section, carrier generation rate, and photoconductivity response time for several different semiconductors including silicon, GaAs, InAs, GaP, and CdS. An electrolyte can be introduced in the gap between the piezoelectric and the semiconductor. This makes it possible to nondestructively monitor the changes in the electrical properties of the semiconductor-electrolyte interface during operation of a semiconductor-electrolyte solar cell. Progress: In connection with real time optical signal processing using surface-acousto-optic interaction, a time integrating correlator with large time bandwidth product was implemented. SAW semiconductor characterization technique has been extended to GaP, CdS-$NiCl_2$ (semiconductor-electrolyte interface) and monitoring of impurity activation in ion-implanted silicon samples.

Recent Publications:

1. P. Das, D.K. Ferry and A.H. Barr, "The Transient Response of Quasi-Two-Dimensional Semiconductors Under Hot Electron Conditions", Surface Science, Vol. 73, pp. 147-155, 1978.

2. R. Bharat, P. Das, R.T. Webster and H. Estrada-Vazquez, "Contactless Measurement of Carrier Generation Rate in Semiconductors", Proceedings of the Topical Conference on Characterization Techniques for Semiconductor Materials and Science, pp. 93-105, 1978.

3. H. Gilboa and P. Das, "Photoconductivity Study of Semiconductors Using the Surface Acoustic Wave Convolver", Solid State Electronics, Vol. 22, pp. 55-62, 1979.

4. P. Das, R.T. Webster, H. Estrada-Vazquez and W.C. Wang, "Contactless Semiconductor Characterization Using Surface Acoustic Waves", Surface Sci. 86 848, 1979.

5. P. Das, R.T. Webster and B. Davari, "Electrical Properties of Semiconductor-Electrolyte (CdS-$NiCl_2$) Using Surface Acoustic Wave Techniques", Appl. Phys. Lett. 34 307, 1979.

6. R.T. Webster, H. Estrada-Vazquez and P. Das, "Study of the Surface Properties of Thermally Oxidized Silicon Using Surface Acoustic Wave Attenuation", Sol. State Elec. 22, 541 (1979).

7. H. Estrada-Vazquez, R.T. Webster and P. Das, "Transverse Acoustoelectric-Voltage (TAV) Spectroscopy of High Resistivity GaAs", J. Appl. Phys. 50 4942, 1979.

8. P. Das, H. Gilboa, K. Varahramyan and R.T. Webster, "Non-destructive Evaluation of Semiconductor Surfaces Using the Surface Acoustic Wave Convolver", Proceedings of the 14th Electrical Electronics Insulation Conference, IEEE Publication No. 79 CH 1510-7-EI, pp. 284-289, 1979.

9. F.M.M. Ayub and P. Das, "Real-Time Signal Processing Using the Side Entry Configuration of Acousto-optic Interaction", SPIE 185 Optical Processing Systems, 110, 1979.

10. F.M. Ayub and P. Das, "Two-Dimensional Image Scanning of Movies Using Surface Acousto-optic Interaction", Optics and Laser Technology, Vol. 11, pp. 87-90, 1979.

NR 372-016, University of Southern California, "Theoretical Studies of the Interface Electronic Properties of Tetrahedrally Coordinated Semiconductors", P.I. - A. Madhukar, (213) 741-6929, N00014-77-C-0397

The overall objective of this program is to seek an understanding of the nature of the electronic properties of surfaces, superlattices and heterojunctions of tetrahedrally bonded semiconductors. Emphasis is placed upon isolating and investigating the influence of (a) atomic geometry and (b) band-edge discontinuity on the interface electronic structure. A tight binding approach is employed. Calculations of the electronic structure of polar-non polar semiconductor heterojunctions and superlattices are under progress. Current calculations also include refined and realistic extensions of the first results relating to the electronic structure of interface vacancy defects reported by us this past year (see report below). Progress: Semi-empirical tight binding calculations of lattice matched heterojunctions between semi-infinite solids have revealed that interface states (in the fundamental band gap) arising from purely chemical bonding effects are highly unlikely for both, usual band line ups as exemplified by the GaAs/AlAs system and unusual band line up as found in the InAs/GaSb system. The latter system reveals a finite density of states at the interface throughout the fundamental band gap regions of the individual materials, thus explaining the observed absence of any interface barrier. Results have also been obtained for the (100) InAs/GaSb superlattices in the thickness range of 12-50^{O}A. They show the observed semiconducting nature, the best fit for the observed superlattice band gaps being obtained for a band edge discontinuity of E_c(InAs)-E_v(GaSb) = -0.06 eV. The electrons and holes are found to be confined within the InAs and GaSb layers respectively, thus giving rise to spatial separation unlike the GaAs/AlAs system. Calculated effective masses (in the (100) plane) for the conduction band show considerable thickness dependent enhancement, consistent with the experiments. Finally, the first results relating to the electronic levels associated with anion or cation vacancy defects at the (110) III-V heterojunctions were obtained. The influence of changes in one kind of interface bond on the defect state arising from the dangling bond of the other nonbonded interface atom were studied. It is found

that those changes in interface geometry (i.e., relaxation of atoms around the defect) which do not significantly influence the host chemical bonds have little (<0.05 eV) influence on the energy of the interface defect state. It is thus inferred that atomic relaxations involving significant (>5%) changes in the host chemical bonds are the important class of relaxations requiring intensive investigation to determine the exact energy and symmetry of the interface vacancy related defect states. Such investigations are under progress. Investigations of the magneto-transport and magneto-optical properties of two dimensionally confined electron and hole gases created in superlattices, heterojunctions and MOS inversion/accumulation layers have also been carried out. A theory for the role of electron-acoustic phonon interaction in cyclotron-resonance has been developed and shown, for the first time, to account for both the temperature and magnetic field dependence of the resonance line width, when the background short ranged impurity scattering is taken into account. A comprehensive investigation of the electron-optical phonon coupling has been carried out and reveals an enhancement (over the bulk coupling strength) due to electron confinement effects, such as loss of certain momentum selection rules in finite structures. This provides partial explanation for enhanced coupling indicated by a variety of experiments. To unambiguously and directly extract the electron - LO phonon coupling from experiments, it was shown that the Resonant Landau Level - Optical Phonon interaction in 2 dimensionally confined systems gives rise to extremely sharp magneto-optical anomalies. Thus a direct measurement of the splitting of the magneto-absorption peak under resonance conditions provides a direct evaluation of the enhanced electron-LO phonon coupling strength. Lastly, a study of the collective modes of oscillation of spatially separated two component plasmas was carried out. It was shown that the acoustic plasmon mode of such a system becomes undamped at long wavelengths, provided the spatial separation exceeds a critical value. It is thus suggested that the double quantum well structure of $GaAs/Al_xGa_{1-x}As$ system offers the possibility of observing the elusive acoustic plasmon.

Recent Publications:

1. "The Electronic Structure of InAs/GaSb(100) Superlattices: Two Dimensional Effects", A. Madhukar and R.N. Nucho, Sol. St. Comm., 32, 331 (1979).

2. "The Electronic Structure of Semi-Infinite III-V Compound Semiconductor Surfaces and Interfaces: Application to InAs/GaSb(110)", N.V. Dandekar, A. Madhukar and D.N. Lowy, J. Vac. Sc. Tech. (Sept./Oct. issue, 1979).

3. "Effective Masses and Two Dimensional Effects in the InAs/GaSb(001) Superlattices", J. Vac. Sc. Tech. (Sept./Oct. issue, 1979).

4. "Electron-Phonon Interaction and Cyclotron Resonance in Two Dimensional Electron Gas", B. Horowitz and A. Madhukar, Sol. St. Comm., 32 (1979).

5. "Electron-Optical Phonon Coupling and Resonant Effects in Magneto-Absorption Behavior of Two Dimensionally Confined Charge Carrier Systems", A. Madhukar and S. Das Sarma, Surf. Sc. (In Press).

6. "Formation of an Anomalous Acoustic Plasmon in Spatially Separated Plasmas", S. Das Sarma and A. Madhukar, Surf. Sc. (In Press).

7. "A Study of the Electronic Structure of Model (110) Surfaces and Interfaces of Semi-Infinite III-V Compound Semiconductors: The GaSb/InAs System", N.V. Dandekar, A. Madhukar and D.N. Lowy, Phys. Rev. (Submitted).

NR 372-017, University of Illinois at Urbana-Champaign, "Defects in Semiconductors", P.I - John D. Dow, (217) 333-3442, or (217) 333-2891, N00014-77-C-0537

Defects in semiconductors produce energy levels which sometimes: lie deep within the fundamental band gaps, trap carriers or excitons, and act as non-radiative recombination centers (converting electrical or optical excitation energy into heat, thereby limiting the efficiencies of devices). The purposes of this work are: (1) to provide a theoretical framework for understanding and identifying deep defects and (2) to prescribe specific methods for altering the non-radiative recombination rates of such defects. Progress: Predictions of the major chemical trends in the energies of deep impurity levels of A_1 and T_2 symmetry have been made for the substitutional point defects in zincblende hosts. The dependence of the energies of these levels on the host and the variation of the energy levels with host alloy composition have been accounted for. The physical nature of deep levels within the fundamental bandgap has been elucidated: these levels are host-like antibonding states. Calculations are in progress for deep levels associated with pairs of substitutional defects in zincblende hosts. Specifically, we are attempting to predict which additional impurities, when paired with a given deep trap, are likely to drive that deep trap shallow. Preliminary results indicate that the host-like nature of deep levels makes it quite difficult to achieve major alterations of their energy levels; although traps that are only moderately deep can be driven shallow by pairing. Predictions of the deep levels in wurtzite hosts are currently being made, and a theory of the change in energy levels resulting from the zincblende to wurtzite transition is being developed. The effects of interfaces on deep impurity levels are being studied. An embedded cluster method is being developed for predicting the vibrational and electronic state densities of ternary semiconducting alloys. A theory of alloy broadening of persistent spectral lines has been developed and applied to one-dimensional alloys; extension of the theory to three dimensions is in progress.

Recent Publications:

1. "Theory of Substitutional Deep Traps in Covalent Semiconductors", H.P. Hjalmarson, P. Vogl, D.J. Wolford, and J.D. Dow. (Submitted).

2. "A Single-Reflection Layer-Scattering Theory of Low Energy Electron Diffraction Spectra", H.P. Hjalmarson, J.D. Dow, and B.J. Mrstik, J, Vac. Sci. Tech, (in press).

3. "Studies in the Theory of Solids", H.P. Hjalmarson, Ph.D. Thesis, University of Illinois (1979).

4. "N Trap in the Semiconductor Alloys $GaAs_{1-x}P_x$ and $Al_xGa_{1-x}As$", D.J. Wofford, J.D. Dow, W.Y. Hsu, and B.G. Streetman, J. Luminescence, 18/19, 863 (1979).

5. "Spectra of Ternary Alloys", C.W. Myles and J.D. Dow, Phys. Rev. Letters 42, 254 (1979).

6. "Theory of Alloys. I. Embedded Cluster Calculations of Phonon Spectra for A One-Dimensional Binary Alloy", C.W. Myles and J.D. Dow, Phys. Rev. B19, 4939 (1979).

7. "Spectra of Binary Alloys", C.W. Myles, and J.D. Dow, Bull. Amer. Phys. Soc. 24, 395 (1979).

8. "Spectra of Ternary Alloys", J.D. Dow and C.W. Myles, Bull Amer. Phys. 24, 395 (1979).

9. "Predictions of deep trap properties in semiconductors", H. P. Hjalmarson and P. Vogl, Bull. Amer. Phys. Soc. 24, 245 (1979).

10. "Interface polar phonon scattering in Si inversion layers", P. Vogl and K. Hess, Bull. Amer. Phys. Soc. 24. 438 (1979).

11. "Application of extended Huckel theory to GaAs, GaP, GaAs:N, and GaP:N", C.A. Swarts, D. L. Miller, D. R. Franceschetti, H. P. Hjalmarson, P. Vogl, and J. D. Dow, Phys. Rev. B (in press).

NR 372-025, University of Colorado, "Properties and Applications of GaInAsP," P.I. - Dr. Russell E. Hayes, (303) 492-6440, N00014-75-C-0472

This project involves an experimental investigation of those aspects of $Ga_xIn_{1-x}As_yP_{1-y}$, grown by liquid-phase epitaxy on InP substrates, that are of prime importance to the use of this material for field-effect transistors, transferred electron oscillators, and other devices. Specific goals include the determination of electron velocity-field data (up to the threshold field) using current-voltage measurements, the establishment of carrier concentration and mobility profiles of LPE quaternary layers, using FET structures, and the evaluation of metal-insulator semiconductor characteristics for anodic oxides grown on the quaternary layers by means of C-V measurements. Progess: The Purcel-Krum method of density and mobility profiling, using an FET structure, has been extended by means of a distributed model that includes the series resistance effect of the channel region. Results of mobility measurements show that optical phonon, ionized impurity, and alloy scattering are not sufficient to explain the temperature dependence of the mobility observed in our samples. Another scattering mechanism with a temperature dependence of $T^{-0.56}$ is needed to explain the results. The characteristics of anodic oxides produced on $Ga_{0.21}In_{0.79}As_{0.45}P_{0.55}$ include a resistivity of about 5×10^{10} Ω-cm, surface state densities in the range of 10^{11} states/cm^2 with capture cross sections of approximately 6×10^{-15} cm^{-2}. Capacitance-voltage measurements were carried out as a function of frequency to determine the time constant of the surface states.

Recent Publications:

(None)

NR 372-026, California Institute of Technology, "Experimental and Theoretical Studies of Radiative and Non-Radiative Processes in Semiconductors", P. I. - Professor T. C. McGill (213) 795-6811, X1849, N00014-75-C-0423.

A combined theoretical and experimental program is directed toward the study of various phenomena in semiconductors due to electron-hole pairs bound to defect and impurities. Theoretical models of the bound exciton and multiexciton complexes are being developed. Transient photoluminescence spectroscopy and tunable laser spectroscopy is being used to test the theoretical models experimentally and determine the excited state spectra of the bound excitons. Tunable laser sources will be applied to GaAs, InP, and Si. A photocapacitance technique using the tunable laser sources is being developed to look at deep levels in these semiconductors. Tunable laser sources will be used to investigate excitation transfer and non-radiative recombination induced defect motion. Progress: The bound exciton spectrum for shallow acceptors in Si is shown to agree with the simple j-j coupling model. The damping of electron-hole droplet motion has been calculated for different scattering mechanisms including polar phonons and impurity scattering. We have measured the thermodynamic binding energy of multiexciton complexes for Li, P, B, and Ga in Si. A systematic investigation of multiexciton complexes in the shallow donor has been carried out. The transient decay of a number of the multiexciton lines have been measured to determine which states have the same initial states. We have calculated the ground state and excited states of bound excitons and the broadening of the bound exciton liminescence line due to interaction with a number of impurities. The tunable laser source has been used to investigate the excited states of the bound excitons for the donor in GaP. Using the theoretical work we have succeeded in identifying the character of the excited states. A theory of Breit-Wigner-Fano resonances due to interference between excited states of an impurity plus optical phonons on the photoconductivity spectrum has been developed and compared with the experimental photoconductivity spectra.

Recent Publications:

1. "Bound Exciton Absorption in Si:Al, Si:Ga and Si:In", K. R. Elliott, G. C. Osbourn, D. L. Smith, and T. C. McGill, Phys. Rev. B17, 1808 (1978).

2. "Edge Luminescence Spectra of Acceptors in Si: Implications for Multiexciton Complexes", S. A. Lyon, D. L. Smith, and T. C. McGill, Phys. Rev. B17, 2620 (1978).

3. "Damping of EHD Motion: I. Deformation Potential Scattering", D. S. Pan, D. L. Smith, and T. C. McGill, Phys. Rev. B17, 3284 (1978).

4. "Damping of EHD Motion: II. Impurity and Piezoelectric Scattering", D. S. Pan, D. L. Smith, and T. C. McGill, Phys. Rev. B17, 3297 (1978).

5. "Time and Spatially Resolved Absorption at 3.4 μm in Highly Excited Germanium", K. R. Elliott and T. C. McGill, Phys. Rev. B18, 963 (1978).

6. "Transients of the Photoluminescence Intensities of the Electron-Hole-Droplets in Pure and Doped Ge", M. Chen, S. A. Lyon, D. L. Smith, and T. C. McGill, Phys. Rev. B17, 4744 (1978).

7. "Thermodynamic Determination of Work Functions of Bound Multiexciton Complexes", S. A. Lyon, D. L. Smith, and T. C. McGill, Phys. Rev. Lett. 41, 56 (1978).

8. "Absorption and Luminescence of the Bound Exciton in Thallium Doped Silicon", K. R. Elliott, D. L. Smith, and T. C. McGill, Solid State Commun. 27, 317 (1978).

9. "Systematics of Bound Exciton and Bound Multiexciton Complexes for Shallow Donors in Silicon", K. R. Elliott and T. C. McGill, Solid State Commun. 28. 491 (1978).

10. "Luminescence of Bound Exciton and Bound Multiexciton Complexes in Si:Li", S. A. Lyon, D. L. Smith, and T. C. McGill, Solid State Commun. 28, 317 (1978).

11. "Transient Decay of Satellite Lines of Bound Excitons in Si:P", A. T. Hunter, S. A. Lyon, D. L. Smith, and T. C. McGill, Phys. Rev. 20, 1 (1979).

12. "Ground State Energies of Bound Exciton for All Mass Ratios", Yia-Chung Chang and T. C. McGill, Solid State Commun. 30, 187 (1979).

13. "Low Lying Excited States of the Bound Exciton in a Spherical Model" Yia-Chung Chang and T. C. McGill, Solid State Commun. 32, 319 (1979).

14. "Excited States of Donor Bound Excitons in GaP", K. R. Elliott and T. C. McGill, Phys. Rev. B20, December 15, 1979.

NR 372-027, Colorado State University, "High Field Electron Transport in Semiconductors," P. I. Professor D. K. Ferry, (303) 491-6600, N00014-78-C-0124

The transport of hot carriers, those carriers heated by an external electric or optical field, is of concern due to the predominance of these carriers in the operation of semiconductor devices, especially high-speed or high-power devices, and devices of submicron dimension. Yet, the current level of understanding of this high-field transport is still in its infancy, particularly in the region of a non-zero collision duration. This is even more true of our understanding of transport and electron states at interfaces. The current program addresses a number of key questions that are important for modern approaches to high-field transport in semiconductors, focusing primarily upon two aspects: the evolutionary development of the hot carrier distribution function and the electron-lattice interaction, particularly in dimensionally constrained systems. These aspects are particularly the ones which dominate transport in the transient dynamic response region, i.e., carrier transport on time scales $\lesssim$ the relaxation time. Progress: In other work at CSU, the basic time and space constraints for physics of small semiconductor devices have been formulated and a basis for a quantum kinetic approach to transport laid out. In this program, we have used this approach to investigate transport in the non-zero collision-duration regime. The collision interactions are modified for the intra-collisional field effect, and the relaxive rates appearing in balance equations must be convolved over an effective collision duration. Also, a path integral form of the quantum kinetic equation has been developed. The role of the non-zero collision duration in transient and overshoot response of the carrier velocity was then examined and the effect of the temporal retardation of the collision interaction probed. We have also applied the above effects to transport and breakdown in silicon-dioxide and have examined transport in the quasi-two-dimensional inversion layer of MOSFETs, examining primarily the trapping of carriers by localized states near the interface.

Recent Publications:

1. "The Transport of Electrons in Quantized Inversion and Accumulation Layers in III-V Compounds", D.K. Ferry, Thin Solid Films 56, 243-252 (1979).

2. "Energy-gap Narrowing and State Filling in Semiconductors Under Intense Laser Irradiation", D.K. Ferry, Phys. Rev. B12, 7033-7037 (1978).

3. "Transport of Electrons in SiO_2 at High Electric Fields", D.K. Ferry, in Proc. Inter. Conf. on Physics of Semiconductors, Edinburgh 1978, (Inst. of Phys. London, 1978) pp. 801-4.

4. "Electron Transport and Breakdown in SiO_2", D.K. Ferry, J. Appl. Phys. 50, 1422-7 (1979).

5. "Balance Equations for High Field Transport in The Finite Collision Duration Regime", D.K. Ferry and J.R. Barker, Solid State Commun. 30, 361-3 (1979).

6. "Self-Scattering, Path-Variable Formulation of High-Field, Time-Dependent, Quantum Kinetic Equations for Semiconductor Transport in the Finite-Collision-Duration Regime", J.R. Barker and D.K. Ferry, Phys. Rev. Letters 42, 1779-81 (1979).

7. "Physics, Synergetics, and Prospects for Self-Organization in Submicron Semiconductor Device Structures," J.R. Barker and D.K. Ferry, in Proc. 1979 IEEE Conf. on Cybernetics and Society (IEEE Press, New York, CH1424-1/79) pp. 762-765.

NR 372-032, Naval Weapons Center, China Lake, California, "Photoinduced Desorption", P.I. - V. Rehn, (714) 939-2898, N00014-79-WR-0196

As part of the Naval Weapons Center's Michelson Laboratory Synchrotron Radiation Project, this contract research is directed toward applying the unique features of synchrotron radiation to Navy research problems. During the year a new technique for detailed study of surface-adsorbate structure was discovered, and we redirected our efforts accordingly. Working at the Stanford Synchrotron-Radiation Laboratory in collaboration with M. L. Knotek of Sandia Laboratory, we found that ions are desorbed from surfaces when core levels of either adsorbate or host are photoexcited. Using an accelerating field and a field-free drift region in front of the microchannel-plate ion detector, the ion arrival time is proportional to $\sqrt{M/q}$, where M is the ion mass and q, its charge. Thus, as the excitation energy specifies the adsorbate bonding site, so the arrival time yields its mass. Further, since the excitation process is simply photoabsorption, the ion yield plotted vs. excitation energy well above the core-level excitation threshold shows extended x-ray absorption fine structure (EXAFS) appropriate to the atomic arrangement near the adsorbate site only. Since the first experiments on H_2O-doped TiO_2 in December 1978, we have looked at other fully valent ionic materials ($SrTiO_3$, SiO_2, Al_2O_3, BeO) and semiconductors (Ge, ZnSe). The technique is most sensitive to hydrogen desorption, and because hydrogen is both important and difficult to study by other techniques, we plan more extensive measurements on hydrogen desorption from insulators, semiconductors and metals in the future. Oxidation processes will be studied also, and we are keenly interested in the role of sulfur on catalytic surfaces as well. Progress: We have demonstrated that an Auger-assisted desorption of positive ions follows excitation of a core hole in either adsorbate or substrate surface atom. Desorption of H^+, OH^+, O^+ and other species has been observed near the excitation thresholds of O (2s) at 24 eV, Ti (3d) at 34 eV, F (2s) at 30 eV, Be (1s) at 111 eV, Si (2p) at 100 eV, Si (2s) at 149 eV, Al (2p) at 73 eV, Al (2s) at 118 eV, O (1s) at 532 eV and others. Electronic excited-

state structure is observed within 15 eV of the threshold, and EXAFS is observed well above threshold.

Recent Publications:

1. "Energy Transfer in Solid Xe and Kr Doped With N_2O", K.M. Monahan and V. Rehn, J Chem. Phys. 68, 3814 (1978).

2. "Photodissociation of XeF_2 in Solid Xe and Kr", K.M. Monahan, V.O. Jones, and V. Rehn, J. Chem. Phys. 7, 2360 (1979).

3. "Photon-Stimulated Desorption of Ions", M.L. Knotek, V.O. Jones, and V. Rehn, Phys. Rev. Lett. 43, 300 (1979).

4. "The Role of Surface Topography in Predicting Scattering at Grazing-Incidence From Optical Surfaces". V. Rehn, V.O. Jones, J.M. Elson, and J.M. Bennett, Nucl. Instrum. Methods (in press).

NR 372-035, Stanford University, "Control of Impurities in the Epitaxial Growth of High Quality GaAs", David A. Stevenson, (415) 497-4251, N00014-75-C-0887

There are three important aspects of this program: the development of and the refinement of a molecular beam sampling technique for mass spectrometry (MBMS) in order to reliably analyze high temperature-atmospheric pressure environments; the application of this technique to analyze growth techniques to improve the reliability of the growth procedures and the quality of GaAs. We have developed a molecular beam sampling technique which is capable of analyzing parts per million levels of gaseous species at atmospheric pressure and at elevated temperature environments ($\sim 900^{o}C$) and have utilized this technique to investigate typical liquid phase epitaxial (LPE) environments. Based on the results of this analysis, we are modifying the LPE growth procedures in order to minimize the impurity incorporation or to minimize any adverse effects of such incorporation. Progress: The MBMS analysis of typical LPE ambients has established that SiO vapor species are consistently at concentration levels close to equilibrium values. The water vapor concentrations, however, are found to vary widely, depending upon the individual system. Since this impurity appears to be most sensitive to process control, we are investigating techniques for controlling and measuring partial pressures of water vapor in the 1 to 500 ppm concentration range. We find good correlation between the MBMS analysis and commercially available water vapor monitors that utilize the capacitance change of an alumina probe; however, the response times of the latter are significantly slower than the MBMS, particularly in the low concentration regime. We have obtained results on the use of small additions of reactive metals (e.g., Zr and Ti) to liquid Ga for the purpose of chemical gettering of oxygen in the LPE growth process. For most growth conditions, these additions to the liquid Ga melt result in p-type GaAs layers, with some rather impressive electronic properties ($\mu_p \sim 800$ $cm^2/Vsec$; $p \sim 10^{14} cm^{-3}$ at $298^{o}K$). Some growth conditions have produced n-type material and with reasonably high mobilities ($\mu_n \sim 7300$ $cm^2/Vsec$; $n \sim 2/10^{15}$ at $298^{o}K$). The incorporation of these impurities has been confirmed by SIMS analysis and more detailed Hall effect and photoluminescence measurements are in progress. It is not certain at the present time whether the major influence of these additions is simply deoxygenation or if these elements introduce new electronically active levels.

Recent Publications:

1. "The Gas Dynamics of a Conical Nozzle Molecular Beam Sampling System", H. Dun, B.L. Mattes, D.A. Stevenson, Chemical Physics, 38, 161 (1979).

2. "Molecular Beam Sampling for Mass Spectrometry", D.A. Stevenson, The UTI Journal of Mass Spectrometry, 2, 1-3 (1979).

3. "Molecular Beam Sampling for Mass Spectrometric Studies of Chemical Vapor Deposition Environments", D. Kisker, H. Dun, D.A. Stevenson, in Proceedings of Seventh International Conference on Chemical Vapor Deposition, 79-3, 530-540 (1979).

NR 372-036, University of Illinois, Chicago Circle, "Deep Level Defects in Semiconductors", P.I. - Dr. S. Sundaram, (312) 996-5346), N00014-78-C-0732

This program will be concerned with the theoretical and experimental investigations of the electronic properties of deep level defects in gallium arsenide (GaAs) and indium phosphide (InP) due to transition metal impurities like chromium and iron. Photoluminescence measurements with and without uniaxial stress will be carried out at various temperatures and these will be complemented by studies on optical absorption. From these measurements, and the symmetry considerations for the site of impurities in the particular semiconductor, the valence states and energy levels of the impurities will be obtained. The models for the radiative recombination mechanisms will be examined. The theoretical work is based on the strong crystal field scheme without simplifying assumptions or restrictions regarding the "pure" d-type nature of the orbitals for the impurity ions. The calculated energy levels will be correlated with the experimental results to obtain the crystal field parameters. The plans for the immediate future call for uniaxial stress measurements of the photoluminescence of GaAs:Cr and high resolution studies of InP:Fe in order to interpret the nature of these defect centers and they will be supplemented by investigations using group-theoretical principles. Progress: The photoluminescence of InP:Fe has been studied and the results have been interpreted on the basis of intracenter transition mechanism for the recombination. Values of crystal field parameters Δ, λ_1, and λ_2 have been derived. The experimental results from optical absorption at low temperatures of the analogous system GaAs:Fe have been analyzed, and crystal field parameters have been obtained based on revised assignments of the absorption data. Using a strong field scheme, a refined treatment for the 3d-transition metal ions in crystals has been carried out and the electrostatic interaction matrices have been derived using Racah's irreducible tensor operator formalism. The present method uses 10 independent Coulomb and exchange integrals instead of only the three Racah parameters A, B, and C (or more correctly only B and C) and also not subjected to the restriction of "pure" d-type orbitals. General formula relating the matrix elements of complementary configurations d^n and d^{10-n} has been derived from group-theoretical considerations. The refined theory has been tested on systems $MgF_2:Co^{2+}$ and $MgF_2:Mn^{2+}$ where detailed optical spectral data were available and in addition to giving complete interpretation of their spectra, first numerical values of the Coulomb and exchange integrals in these systems have been calculated. The matrix elements in the improved theory along with results of cluster calculations have been used to obtain the energy levels of GaAs:Cr^{2+} and GaAs:Cr^{3+} and compared with results of earlier theories.

Recent Publications:

1. "Theory of Optical Spectra of 3d-Transition Metal Ions in Solids", R.R. Sharma and S. Sundaram, American Physical Society Meeting, Chicago, Illinois 19-23 March 1979.

2. "Transition Metal Ions in Crystals: A Refined Treatment and Deduction of Coulomb and Exchange Interaction Constants", R.R. Sharma and S. Sundaram, Solid State Comm. 31, December (1979).

3. "Theory of Charge-Transfer for the Electronic Structure of Cr^{2+} in GaAs", Maria Viccaro, R.R. Sharma and S. Sundaram, American Physical Society Meeting, Chicago, Illinois, 21-24 January 1980.

NR 372-048, Naval Research Laboratory, "First-Principles Investigation of the Electronic Structure of Semiconducting Materials", P.I. - Barry M. Klein, (202) 767-3934, N0001479WR90028

In order to do theoretical investigation of the fundamental properties of semiconducting and insulating materials it is important to have a first-principles representation of the band structures of the ordered crystals. Having such a capability would enable theoreticians to study effects due to doping and crystal deformation without recourse to using experimental results. Most of the previous band structure calculations performed for semiconducting and insulating crystals have been done using semi-empirical pseudopotential techniques. The present research will make use of local exchange-correlation formalisms together with ab initio band structure approaches such as the self-consistent discrete variational method (DVM), and the linear combination of gaussian orbitals method (LCGO) to generate band energies and wave functions for a number of semiconducting materials in the diamond and zincblende structures. These include: Si, Ge, Sn, GaAs, GaP, GaSb, InP, InAs and InSb. By comparing the calculated charge densities, optical properties and band effective masses with experiment the quality of the band structure results will be critically examined. Progress: Self-consistent DVM and LCGO programs have been constructed for diamond and zincblende structure crystals. Band structure results using the DVM have been completed for Si and GaAs. They show good agreement with experiment as to band orderings, energy gaps, and shapes of the electronic densities-of-states. Although both the DVM and LCGO methods use crystal potentials which are intrinsically non-spherical in the whole unit cell, in the former the potentials are approximated by solving Poisson's equation for overlapping spherically averaged charge densities. In the LCGO method, this approximation is avoided. Hence, even though our DVM results to date look quite good, we cannot be definitive regarding the efficacy of the ab initio methods until results from the LCGO program are available. Such calculations are presently being performed and will be available shortly for the above-mentioned semiconducting materials.

Recent Publications:

None

NR 372-051, Brooklyn College of CUNY, "Piezo-Optical Determination of Deformation Potentials Relevant to Transport Properties Calculations of Multivalley Semiconductors", P.I. - Dr. Fred H. Pollak, (212) 780-5356, N00014-78-C-0890

An investigation of the stress-dependence of the indirect absorption process can yield valuable information concerning the relative contributions of the phonon-assisted electron and hole scattering mechanisms to the absorption process. These parameters are related to intervalley scattering mechanisms in multivalley semiconductors and hence are important in the calculations of the high field transport properties of these materials. Application of a uniaxial stress along various crystallographic directions affect these two processes (electron-phonon (EP) to hole-phonon (HP) scattering) in a different manner. By measuring the stress-dependence of the indirect absorption process the ratio of the EP to HP strength can be obtained. Progress: Using the sensitive technique of wavelength modulated absorption we have measured the stress-

dependence of the indirect process in Si (TO-phonon) and Ge (LA-phonon) at 77°K. We have obtained a value of 1.4 for the EP_{TO} to HP_{TO} matrix element in Si and 0.16 for the EP_{LA} TO HP_{LA} strength in Ge. Work is being completed for GaP.

Recent Publications:

1. "Piezo-Spectroscopic Determination of the Ratio of Electron-TO Phonon to Hole-TO Phonon Interaction in Silicon", F.H. Pollak, A. Feldblum, H.D. Park and P.E. Vanier, Solid State Comm. 28, 161 (1978).

2. "Piezo-Spectroscopic Determination of the Electron-Phonon to Hole-Phonon Interaction in Si and Ge", F.H. Pollak, A. Feldblum, H.D. Park and P.E. Vanier, Proc. 14th Int. Conf. Physics of Semiconductors, Edinburgh, 1979, ed. by B.L.H. Wilson (Institute of Physics, London, 1979) p. 867.

NR 372-055, Princeton University, "Semiconductor Surfaces", P.I. - Antoine Kahn, (609) 452-4642, N00014-75-C-0394

Our work is part of a considerable effort in surface science to understand the mechanisms and implications of the gas-solid and metal-solid interactions on semiconductor compounds. More specifically, we study the effects on the surface structure of zincblende semiconductor compounds (GaAs(110), InP(110), ZnTe(110)), of oxygen chemisorption and metal (Al,Au) evaporation. Low Energy Electron Diffraction (LEED) is the primary tool used in this investigation. We will use this technique in this research to detect and intrepret changes at the gas-solid or metal-solid interface. A number of parameters (temperature of the substrate, exposure time to oxygen, rate of evaporation of the metal) will be varied in the experiment and subsequent results will be correlated with results obtained with other experimental techniques (Photoemission Spectroscopy). Progress: During the past year, we studied the order-disorder effect of oxygen on GaAs(110). Using crystals cleaved in ultra high vacuum, we found pronounced changes in the LEED pattern when the oxygen exposure reached $5\ 10^2$ toor sec. A computed simulation of the problem revealed the presence of a thin amorphous oxide layer (1-3Å) covering a very ordered GaAs lattice relaxed to its bulk structure. A complete analysis of the changing LEED pattern was given for exposures ranging from 10^{-2} to 10^6 torr sec. Furthermore, the kinetics of the reaction was found to be appreciably increased (100 times) by the degree of excitation of the O_2 gas.

Recent Publications:

1. "LEED Analysis of the Atomic Geometry of ZnO($10\bar{1}0$)", Phys. Rev. B15, 4865 (1977) with C.B. Duke, A.R. Lubinsky, S.C. Chang and B.W. Lee.

2. "Some Thoughts on the Existence of Empty Surface States and the Effect of Surface Order on Sorption", J. Vac. Sci. Tech. 14, 865 (1977), with E. So and M. Bonn.

3. "The Structure of Tetrahedrally-Coordinated Semiconductor Surfaces by LEED Analysis", Proc. of the 3rd Intern. Conf. on Solid Surfaces, (R. Dobrozemsky, Vienna, 1977), Vol. 1, p. 533, R. Dobrozemsky, F. Rüdenauer, F.P. Viehböck and A. Breth, eds.

4. "A Comparison of LEED Intensity Data From Chemically Polished and Cleaved GaAs(110) Surfaces", Surface Science 69, 735 (1977), with P. Pianetta, I. Lindau and W.E. Spicer.

5. "Evidence for Subsurface Atomic Displacements of the GaAs(110) Surface from LEED/CMTA Analysis", Surface Science 71, 387 (1978), A. Kahn, G. Cisneros, and M. Bonn.

6. "Subsurface Atomic Displacements at the GaAs(110) Surface", J. Vac. Sci. Technol. 15, 580 (1978), A. Kahn, E. So, P. Mark and C.B. Duke.

7. "Surface Composition and Fabrication of an Oxide-Free $Ga_{1-x}Al_xAs$ Schottky Barrier," Appl. Phys. Lett. 32 751 (1978), B.W. Lee and J.L. Yeh.

8. "Surface and Near Surface Atomic Geometry of GaAs(110)", J. Vac. Sci. Technol. 15, 1223 (1978), A. Kahn, E. So, C.B. Duke and R.J. Meyer.

9. "Schottky Barriers on Ordered and Disordered Surfaces of GaAs(110)", J. Vac. Sci. Technol. 15, 1344 (1978), A. Amith.

10. "The Effect of Surface Index and Atomic Order on the GaAs-Oxygen Interaction", Thin Solid Films 56, 19-38 (1979) W.F. Creighton.

11. "Surface Composition and Characteristics of Oxide-Free $Ga_{1-x}Al_xAs$(110) Schottky Barriers", J. Vac. Sci. Technol. 16, 514 (1979), B.W. Lee, J. Jou, J.L. Yeh and E. So.

12. "Analysis of LEED Intensities from ZnTe(110)", J. Vac. Sci. Technol. 16, 647 (1979), C.B. Duke, R.J. Meyer, A. Paton, E. So and J.L. Yeh.

13. "Dynamical Calculation of Low-Energy Electron Diffraction Intensities From GaAs(110): Influence of Boundary Conditions, Exchange Potential, Lattice Vibrations and Multilayer Reconstructions", Phys. Rev. B19, 5194 (1979), R.J. Meyer, C.B. Duke, A. Paton, A. Kahn and E. So.

14. "Order-Disorder Effects in GaAs(110)-Oxygen Interaction: A LEED-UPS Analysis", A. Kahn, D. Kanani, P. Mark, P. Chye, C. Su, I. Lindau and W. Spicer, Surface Science 87 (1979) 325.

15. "Order-Disorder Effect in GaAs(110)-Oxygen Interaction: A LEED Analysis II", A. Kahn, D. Kanani and P. Mark, Surface Science (to be published).

NR 372-063, State University of New York at Buffalo, "Statistical Mechanics of Two-Dimensional Electron Fluids", P.I. - A. Isihara, (716) 636-2007, N00014-79-C-0451

A new promissing theoretical approach is being developed for the prominent many body effects on the electronic properties of the 2D electron systems such as formed in MOS interfaces. The overall objective is in developing fundamental and profound many body theory of 2D electrons to obtain explicitly the energy, chemical potential, effective g factor and mass, etc. and in understanding the electronic properties of these systems. The project starts with the quantum mechanically degenerate case for absolute zero and will be extended to low but finite temperatures for all density so that a phase diagram be obtained. For absolute zero, a rigorous theory of the second order exchange energy has been developed. It is applicable to the 3D case and can simplify the theory of Onsager et al. The first order exchange energy has been evaluated for low but finite temperatures. It has been discovered that it has a characteristic logarithmic term. The presence of such a term is very important because it may explain the general low density failure of previous many body theories of the effective g-factor and mass. A new electrostatic analogy for the dielectric function has been found. It will help the evaluation of the grand partition function for density. Progress: At the Third International Conference on the Electronic Properties of 2D Systems held in Yamanaka, Japan, in September, 1979, the following new results were reported:

1. Fundamental differences are found between the ground state energies which are

obtained with and without iteration.

2. The chemical potentials of 2D and 3D electrons behave differently in a magnetic field.

3. The effective g factors of the 2D and 3D electrons behave similarly as functions of density. The latter case has yet to be investigated by experiment. A possible explanation of the general low density failure of the previous theories of the effective g factor and mass was given. At the International Symposium on Fundamental Problems of Theoretical and Mathematical Physics, held in Dubna, USSR, August, 1979, a new formula for the effective mass of 2D electrons in strong magnetic fields and some other new results were presented.

Recent Publications:

1. "Thermal and Magnetic Properties of 2D Electrons", A. Isihara, Proc. Int. Conf. 2D EP, Yamanaka, Japan, 1979, to be published.

2. "Electron Gas, Classical Fluid and Liquid Helium", A. Isihara, Proc. Int. Symp. on Fund. Problems of Theo. and Math. Phys., Dubna, USSR, 1979, to be published.

3. "Exact Evaluation of the Second Order Exchange Energy of a 2D Electron Fluid", Liderio Ioriatti and A. Isihara, to be published.

4. "Two-Dimensional Electron Gas at Finite Temperature", A. Isihara and T. Toyoda, to be published.

5. "Energy Spectrum and Phase Velocity in Two- and Three-Dimensional Liquid Helium II", A. Isihara et al, to be published.

NR 372-064, University of Missouri, "Very Low Frequency Quantum Electronics, 1/f Noise and Infra-Quantum Physics", P.I. - Peter H. Handel, (314) 453-5931, N00014-79-C-0405

1/f Noise, the dominant component of electric current noise at low frequencies, is still not understood. However, a simple calculation shows that infrared divergent coupling to massless quanta such as photons, phonons, electron excitations in metals, generates current fluctuations with a 1/f spectrum made convergent by infrared radiative corrections. This result opens up the possibility of infra-quantum spectroscopy (e.g., of photons of 10^{-2} Hz) by simple current noise spectroscopy, and explains the absence of a low frequency limit, the ubiguity of 1/f noise, and its frequent appearance in mobility fluctuations. The purpose of the present research project (started on May 1, 1979) is to determine the extent to which the observed 1/f spectra can be described this way, and to improve the theory. Progress: Recently the theory was generalized to include the actual case of thermal equilibrium of the background of infra-quanta at any finite temperature, the theory was presented in a simplified form (without using creation and annihillation operators) and used conceptually to explain 1/f frequency fluctuations in quartz crystal resonators. Most recently, the characteristic functional of quantum 1/f noise was derived.

Recent Publications:

1. "Nature of 1/f Frequency Fluctuations in Quartz Crystal Resonators", Solid State Electronics, in press.

NR 372-066, University of Illinois, "Properties of Lattice Matched Heterojunctions", P.I. - Professor G. E. Stillman, (217) 333-3097, N00014-77-C-0653

Heterostructures utilizing the InGaAsP-InP lattice-matched quaternary alloy system are fabricated using LPE growth techniques. The characteristics of these structures such as lattice-mismatch, bandgap difference, hetero-junction band discontinuities, interface states, interface abruptness, and spectral response characteristics of photodiode structures are studied. The results of the characterization measurements will be correlated with the growth techniques to determine the optimum conditions for fabrication of devices in the InGaAsP quaternary semiconductor systems. Progress: Careful studies of the distribution coefficients required for the growth of lattice-matched InGaAsP-InP structures have shown that in addition to depending on the substrate orientation, growth temperature, and alloy composition, they also depend on the dopant used in the growth solution. The influence of the dopant on the distribution coefficients must be taken into account for the growth of accurately lattice-matched multiple heterojunctions. The four common LPE growth techniques, step-cooling, equilibrium-cooling, supercooling, and two phase solution have been studied, and it has been shown that in general all of the growth techniques which involve growth with changing temperatures result in compositionally graded layers. Auger profiles of the heterojunction interfaces have shown that there is significant grading in a 100 Å wide interface region in closely lattice-matched heterojunctions and that the grading is even wider in mismatched heterojunctions. This interfacial grading may be responsible for the large reverse currents observed in heterojunction diodes. The influence of this grading region has been avoided by forming p-n junctions by Be-ion implantation into InGaAsP quaternary layers. This technique has resulted in the lowest dark currents achieved in quaternary p-n junction photodetectors and avalanche photodiodes.

Recent Publications:

1. "The Influence of Growth-Solution Dopants on Distribution Coefficients in the LPE Growth of InGaAsP", M. Feng, M.M. Tashima, L.W. Cook, R.A. Milano, and G.E. Stillman, Appl. Phys. Lett. 34, 91-93 (1979).

2. "The Influence of LPE Growth Techniques on the Alloy Composition of InGaAsP", M. Feng, L.W. Cook, M.M. Tashima, T.H. Windhorn, and G.E. Stillman, Appl. Phys. Lett. 34, 292-295 (1979).

3. "Auger Profile Study of the Influence of Lattice Mismatch on the LPE InGaAsP-InP Heterojunction Interface", M. Feng, L.W. Cook, M.M. Tashima, and G.E. Stillman, Appl. Phys. Lett. 34, 697-699 (1979).

4. "Be-Implanted 1.3-μm InGaAsP Avalanche Photodetectors", M. Feng, J.D. Oberstar, T.H. Windhorn, L.W. Cook, G.E. Stillman, and B.G. Streetman, Appl. Phys. Lett. 34, 591-593 (1979).

5. "Lattice Constant, Bandgap, Thickness, and Surface Morphology of InGaAsP-InP Layers Grown by Step Cooling, Equilibrium-Cooling, Supercooling, and Two-Phase-Solution Growth Techniques", M. Feng, L.W. Cook, M.M. Tashima, and G.E. Stillman, to be published in Journal of Electronic Materials.

NR 372-068, Max-Planck-Institut für Festkörperforschung Hochfeld-Magnetlabor Grenoble, "International Conference on Impurity Bands in Semi-Conductors", P.I. - Professor G. Landwehr, France (76) 87.98.42, N00014-79-G-0072

Recent progress in the field of impurity conduction made it advisible to organize an

international conference with workshop character to discuss outstanding problems. The conference, which was mainly sponsored by the Deutsche Forschungsgemein-schaft (Bonn), was held at the University of Würzburg, Federal Republic of Germany, from October 8th to 11th, 1979. Emphasis was on transport and optical properties of heavily doped semiconductors and on the metal-non metal transition. Progress: The conference turned out to be very timely and about 80 persons attended. In addition to 22 invited papers a few contributions were presented at a poster session. One of the main subjects of the conference was the discussion of electron correlation in un-compensated systems and the significance of electron-electron interaction in various transport effects. The behaviour of the conductivity on the insulating side of the Mott-Anderson transition was treated, also the problem of the Hall effect. Another subject presented was the impurity band conduction in silicon inversion layers. The conference helped to clarify a number of problems but it became clear that our present knowledge of heavily doped semiconductors is incomplete.

Recent Publications:

None

NR 372-070, Case Western Reserve University, "Electronic Structure and Properties of Silicon-Nitride Insulating Films", Dr. V. J. Kapoor, (216) 368-4081, N00014-79-C-0677

The primary objective of this research is to develop a quantitative understanding of the electronic structure and properties of the silicon nitride films. This research involves parallel efforts on internal photoelectric-effect spectroscopy, Auger electron spectroscopy and theoretical studies to investigate the defects and/or impurities related traps in the nitride films. An extensive program of control and characterization of the microconstitution of the silicon nitride is being pursued, correlating controlled variation of the sample fabrication process with impurities/defects related electronic properties and with the chemical nature of metal-nitride-oxide-semiconductor (MNOS) structures. Progress: Internal photoelectric-effect technique has been developed as an experimental technique for investigating the electron charge trapping and charge storage characteristics of the insulating thin films of Si_3N_4 in a MNOS device configuration. The measurement program has been developed around significant advances in instrumentation employing a computer based real time digital data processing and analysis system. The trapped electronic charge has been determined to be uniformly distributed throughout the Si_3N_4 film with a midfilm concentration of $3.9 \times 10^{17}/cm^3$. Five well defined electron trap levels within the Si_3N_4 at 2.48, 2.76, 3.05, 3.35 and 3.75 eV below the Si_3N_4 conduction band edge have been determined. Preliminary scanning Auger electron spectroscopy studies in conjunction with argon-ion sputtering has been performed to investigate the stoichiometry and the chemical nature of the nitride film and to establish any correlation between the nitride traps and the chemical nature of the films.

Recent Publications:

1. "Charge Storage in the Nitride Layer of a Biased MNOS Device", V.J. Kapoor, R.A. Turi, A.V. Kordesch and W.H. Ko, Bull. Am. Phys. Soc. 24, 495 (1979).

2. "Energy Distribution of Memory Traps in the MNOS Structures", A.V. Kordesch, V.J. Kapoor and W.H. Ko, Bull. Am. Phys. Soc. 24, 496 (1979).

3. "Auger Depth Profiling of Thick-Oxide MNOS Devices", R.S. Bailey, S.R. Smith and V.J. Kapoor, Bull. Am. Phys. Soc. 25 (March 1980).

4. "Energy Distribution of Electron Trapping Centers in LPCVD Silicon-Nitride Films", V.J. Kapoor and S.B. Bibyk, Journal of Appl. Physics (submitted for publication).

5. "Electronic Charge Trapping in Thick-Oxide MNOS Devices", V.J. Kapoor and W. Morris, Bull. Am. Phys. Soc. 25, 313 (1980).

NR 372-071, IBM, San Jose, CA, "Electronic Structure and Properties of Semiconductor Interfaces", P.I. - Dr. F. Herman, (408) 256-6254, N00014-79-C-0814

One of the most active and exciting branches of current-day solid state physics is the study of semiconductor surfaces, overlayers, and interfaces. Because these regions play vital roles in modern semiconductor technology (integrated circuits, heterojunction lasers, solar cells, etc.), their physical, chemical, and metallurgical properties are being extensively studied. Moreover, semiconductor heterojunctions and superlattices of novel design are now being fabricated by molecular beam epitaxy. These configurations exhibit striking electronic, optical, and magnetic properties which are of considerable scientific as well as technological interest. By all indications, experimental and theoretical research in this area will continue to grow, with strong emphasis being placed on the development of a fundamental understanding of the electronic structure and related physical properties of semiconductor interfaces. (In the interest of brevity we will refer to chemisorbed layers on solid surfaces, solid-vacuum interfaces, metal-semiconductor barriers, polymorphic barriers, heterojunctions, etc., as interfaces in what follows). The common theme of this study is the determination of the localized electronic states associated with realistic models of important classes of interfaces. We are particularly interested in elucidating the nature of the intrinsic localized interface states, including their energy level structure and spatial extent. We would like to know whether these energy levels lie within the forbidden band or not, and whether they can act as traps or recombination centers. We are also interested in determining the electronic structure of selected chemical and structural imperfections (impurities, dangling bonds, dislocations) when they occur at interfaces, as well as their experimental consequences. By examining a number of realistic interface situations, we hope to obtain some insight into the general nature of intrinsic and extrinsic interface states, as well as specific information for the geometries and chemical constituents actually investigated. It is anticipated that our studies will prove useful in interpreting electronic and optical measurements of interfacial phenomena, and in suggesting new types of experiments on interfaces and superlattices. Progress: New Contract

Recent Publications:

None

NR 372-074, Xerox Palo Alto Research Center, "Atomic and Electronic Structures of Semiconductor Surfaces and Defects", P.I. - D.J. Chadi and R.M. Martin, (415) 494-4136, N00014-79-C-0704

The objective of this investigation is a better understanding of the atomic positional configuration and the electronic states of semiconductor surfaces, interfaces and defects. The approach will be to determine equilibrium relaxed atomic positions by minimizing the total energy, and then to apply the results to calculate the associated electronic energy levels. This will be done in particular to study the structural and electronic problems associated with relaxations and reconstructions on semiconductor surfaces, and defects, such as vacancies, steps or impurities at the surface. Progress: New Contract

Recent Publications:

None

NR 372-076, University of Texas, Austin, "Synthesis of Useful Electronic Structures Using Solid Phase Reactions Near Surfaces", P.I. - R.W. Bene' (512) 471-1225 and R.M. Walser (512) 471-5733, N00014-75-C-0916

Our long range goal is to be able to take into account and influence interfacial reactions that take place at subeutectic temperatures in thin film material systems, in order to fabricate new device structures in the microelectronics area, and to understand in more detail device reliability and aging. Our more immediate goal is to understand the path selection processes and kinetics of solid state reactions which lead to crystalline phase formation. The approach we are taking is twofold. First we are attempting to combine what is known about reactions from thermodynamics, nonequilibrium chemistry, surface physics and biological growth in a coherent manner in hopes we may arrive at an overall description of these solid state processes. This approach goes beyond a "maximization of free energy" which clearly is not the selection process for interfacial phase formation where a fast reaction path selection process is operating. The second approach we are taking is experimental. We are basically making measurements of thin metal films on Si and α-Si on crystal Si in order to check some of the hypotheses which we arrive at from the first approach. We have found evidence for a predicted glassy phase formation preceeding first phase nucleation in a variety of metal-silicon systems, and we have recently found for the near noble metal-Si systems that first nucleation may be an electronically driven transition out of a two dimensional glassy metal phase. Work is continuing on determining the properties of the thin film phases which occur prior to crystalline phase nucleation for a variety of metals deposited on Si. In particular, we are extending the measurements made in the prenucleation region to include TED, TEM, resistivity, 1/f noise, EPR spectroscopy and inelastic tunnelling on the systems of Si with Ni, Co, Pt, Pd, Fe, Ti and Cr. Progress: We have made progress in several areas that have improved our basic understanding of structure-determining energy transfer. Specifically we are determining how conventional long range order is eliminated by the dynamic energy transfer in heavy ion bombardment and laser irradiation. Experimentally we have demonstrated that amorphous silicon can be produced by irradiation with $\sim$20 psec pulses of 1.06μ protons. The experimental parameters of the process have been determined and a model is being developed. We have begun a study of ion-beam deposited transition metals. We are initially concentrating on understanding how thin glassy layers are produced in the nickel silicon system. We have been able to reproducibly obtain amorphous layers by annealing that have demonstrated threshold and memory switching.

Recent Publications:

1. R.W. Bene', R.M. Walser, J.C. Hu, "Relationship of Metal-Semiconductor Transition to First Compound Nucleated at the Interface of a Thin Film Transition Metal on a Silicon Sub-Substrate", Physics of Semiconductors, pp. 773-776 (1979).

2. R.W. Bene', G.S. Lee, R.M. Walser and J.C. Hu, "Cobalt on Silicon: Evidence for Electronically Stimulated Compound Nucleation", submitted to Journal of Applied Physics.

NR 372-077, California Institute of Technology, "The Application of Ion Implantation to Compound Formation", P.I. - Professors J.W. Mayer and M-A. Nicolet, (213) 795-6811

exts. 1817 and 1803, N00014-75-C-0912

The process of ion implantation and the small accelerators developed to perform ion implantations have a much larger potential field of application than their present conventional use for the doping of semiconductors. The general objective of this study is to investigate possible alternative uses of ion beams and their interactions with solids. Specifically, the effort here focuses on two aspects: (i) investigations of the ultimate limits of concentrations of implanted species in a target and (ii) instrumental developments to allow for backscattering analysis studies on an ion implantation system. For the investigation of the high-dose implantations, the approach has been to study the concentration by MeV backscattering spectrometry of implanted species in elemental and in binary compound targets for light and heavy mass bombarding species. The instrumental effort concentrated on the installation of a second beam leg for backscattering studies at low energies. Progress: The maximum concentration of the implanted species has been determined to be set by ion-induced erosion (sputtering) of the implanted layer, and is given roughly by S^{-1}, where S is the sputtering yield. The concentration extends over a depth comparable with the ion range. Good agreement has been found between calculations and experiments, such as 150 keV Au implanted in Cu or Fe. High-dose implantations with inert gases ultimately leads to the formation of bubbles. These have been found to form at the metal-silicon interface when the implantation is performed through a thin metal film evaporated on silicon. Significant intermixing of the metal and the silicon is a generally observed phenomenon. Preferential sputtering in binary silicides has also been observed and measured. Preferential sputtering and intermixing of layers by ion beams have a detrimental effect in sputter-depth-profiling of thin-film structures and interfaces. A model has been developed that describes these effects phenomenologically and quantitatively. On the instrumental effort, an accurate method of charge integration and a simple diagnostic procedure to test the dosimetry of an ion implantation system have been developed. The beam line for low energy backscattering experiments is approaching completion.

Recent Publications:

1. "Limits of Composition Achievable by Ion Implantation", Z.L. Liau and J.W. Mayer, Journal of Vacuum Science and Technology, 15, 1629 (1978).

2. "Inert-Gas Bubble Formation in the Implanted Metal/Si System", B.Y. Tsaur, Z.L. Liau and J.W. Mayer, Journal of Applied Physics, 50, 3978-3984 (1979).

3. "Influence of Atomic Mixing and Preferential Sputtering on Depth Profiles and Interfaces", Z.L. Liau, B.Y. Tsaur and J.W. Mayer, Journal of Vacuum Science and Technology, 16, 121-127 (1979).

4. "Ion Bombardment Effects on Material Compositions", Z.L. Liau, and J.W. Mayer, to be published in Ion Implantation in Materials Science and Technology, J.K. Hirvonen, Ed., Chapter 2.

5. "Surface Layer Composition Changes in Sputtered Thin Film Alloys and Compounds", Z. L. Liau, in Proceedings of the Symposium on Thin Film Phenomena-Interfaces and Interactions, John E. Baglin and John M. Poate, Eds., (Electrochemical Soc. Inc., Princeton, 1978), p. 361.

6. "Electron and Ion Currents Relevant to Accurate Current Integration in MeV Ion Backscattering Spectrometry", S. Matteson and M-A. Nicolet, Nuclear Instruments and Methods, 160, 301-311 (1979).

7. "Diagnostic Test for Ion Implantation Dosimetry", S. Matteson, D.G. Tonn and M-A. Nicolet, Journal of Vacuum Science and Technology, 16, 882-883 (1979).

NR 372-079, Massachusetts Institute of Technology, "Research on Submicrometer Structures, Fabrication Technology and Interdisciplinary Applications", P.I.- Henry I. Smith, (617) 253-6865, N00014-79-C-0908

The general problem area of this research is artificial microstructures and applications. The six areas listed below will be investigated:

1. Fundamental Limitations of Microfabrication-Structures of 50 to 100 Å Linewidths. Means of generating and replicating patterns in this size regime will be developed. Methods to be used will include (a) scanning electron beam lithography, (2) spatial period division using soft x-rays, (3) shadowing combined with x-ray replication. Processing methods (i.e., etching, doping, deposition, growth) will also be developed in order that useful relief structures in this regime can be produced.
2. Organic Molecules-Site Specific Properties. It has been demonstrated that certain organic molecules can be made to absorb at specific sites on a substrate in accordance with a pattern written by STEM lithography. We will do further exploratory work in preparing surface sites for attachment of specific parts of organic molecules.
3. X-Ray Lenses. Focusing devices for soft x-rays are being produced through fabrication of Fresnel zone plates, which are generated by electron beam lithography, and replicated by x-ray lithography. We will address opportunities for use of these focusing elements.
4. Submicrometer Structures and Liquid Crystal Research. It has been demonstrated that submicrometer spatial-period surface-relief gratings in SiO_2 have a very strong aligning effect on nematic and smectic liquid crystals. The contractor proposes to investigate the mechanical properties and surface interactions, statistical mechanics of phase transitions in liquid crystals aligned by submicrometer structures, and possibility of alignment of lyotropic phases and nematic polymers.
5. Graphoepitaxy. Oriented crystal growth has been obtained on amorphous substrates using submicrometer spatial period relief features. This technique, termed graphoepitaxy, will be further investigated. Basic studies will be conducted on thin film nucleation, growth and orientation on artificial surface relief structures.
6. Attachment and Properties of Molecules on Submicrometer Structures. This study will address the problems of attachment of molecules to submicrometer structures, the detection and characterization of their locations, and processing modifications such as subsequent polymerization and cross linking of the deposited molecules. Multistep procedures will be investigated in which several different selected areas on the same substrate can be treated. Progress: New Program.

Recent Publications:

None

NR 372-095, Colorado State University, "Compound Semiconductor Surfaces and Interfaces", P.I. - Carl W. Wilmsen, (303) 491-6015/491-5225, N00014-76-C-0387

This research investigates the kinetics of dielectric - III-V compound semiconductor interface formation. For grown oxides, this is accomplished by Auger/ESCA profiling thermal and anodic oxides of increasing oxide thickness, starting with the bare substrate. In this way, the oxide growth morphology and oxide/semiconductor interface formation are observed. For deposited insulators Auger/ESCA profiles are obtained

from film deposited under various conditions and after different post deposition treatments. Progress: The anodic oxide/GaAs interface has been shown to consist of an interfacial layer of Ga_2O_3 ($\sim$ 30-35 Å thick) with some elemental As. This interface has been shown to form during the nucleation and island growth stage of the oxide. The interface remains essentially unchanged after the islands seal over the surface. The anodic oxide/InP interface, on the other hand, has been found to change with growth after the island stage. The initial interface contains P_2O_5, In_2O_3 and elemental P. Upon increased oxide growth, the interfacial P oxidizes to increase the P_2O_5 content. Models for the interface formation for anodic and thermal oxides and CVD deposition of SiO_2 and SiON on InP and GaAs have been proposed. The model has been partially verified by the Auger/ESCA profiles. In the coming year, emphasis will be placed on the thermodynamics and kinetics of interface formation, particularly for InP.

Recent Publications:

1. C.W. Wilmsen, L.G. Meiners and D.A. Collins, "Single and Double Layer Insulator Metal-Oxide-Semiconductor Capacitors on Indium Arsenide", Thin Solid Films 46, 331 (1977).

2. C.W. Wilmsen and R.W. Kee, "Analysis of the Oxide/Semiconductor Interface Using Auger and ESCA as Applied to InP and GaAs", J. Vac. Sci. Tech. 15, 1573 (1978).

3. R.W. Kee, K.M. Geib, C.W. Wilmsen and D.K. Ferry, "Interface Characteristics of Thermal SiO_2 on SiC", J. Vc. Sci. Tech. 15, 1520 (1978).

4. C.W. Wilmsen, and R.W. Kee, "The Improvement of Grown Oxides for the Surface Protection of III-V Compounds", Thin Solid Films 51, 93, (1978).

5. C.W. Wilmsen, R.W. Kee, J.F. Wager, J. Stannard and L. Messick, "Interface Formation of Deposited Insulator Layers on GaAs and InP", Thin Solid Films 64 49 (1979).

NR 372-107, Yale University, "Determination of Nonequilibrium Phonon Temperature Under High-Field Conditions by Laser-Raman Scattering", P.I. - R. K. Chang, (203) 432-4470, N00014-76-C-0643

Electron-phonon interactions (H_{ep}) affect high-field transport properties of semiconductors. Intervalley electronic transitions within the conduction band ($\Gamma^C \rightarrow L^C$, $L^C \rightarrow L^{C'}$, $L^C \rightarrow X^C$) involve creation or destruction of phonons with large $\vec{k}$. Since the anti-Stokes two-phonon Raman peaks are related to the population of phonon pairs with large $\vec{k}$, we propose to use the ratio of anti-Stokes-to-Stokes intensity of two-phonon Raman Shifts for the determination of the nonequilibrium temperature of phonons of specific $\vec{k}$ when pumped by the electrons. The electrons can be excited in two ways: (1) high intensity pulsed radiation (argon laser with cavity dumper) with $\hbar\omega > E_L$ without an applied electric field; and (2) high intensity pulsed radiation with an applied electric field below the Gunn threshold. Progress: The cavity dumper needed for the experiment has a ten months delivery date. While waiting for the arrival of this equipment, we have investigated the following: (1) time development of the surface enhanced Raman scattering (SERS) of various molecules during the oxidation-reduction process of an electrolyte cell with Ag electrodes; (2) the role of surface plasmon in SERS; and (3) in heavily doped p-type GaSb and InSb, the coherent interaction (Fano-type) between the $\vec{k}$-induced LO phonon scattering and the single particle excitation of the holes.

Recent Publications:

1. "Laser-Raman Optical Multichannel Analyzer for Transient Gas Concentration Profile and Temperature Determination", P.C. Black and R.K. Chang, AIAA Journal 16, 295 (1978). NTIS No. N78-13405, Springfield, Va., 1978.

2. "Resonant Two-Phonon Scattering in GaSb near the E_1 and $E_1 + \Delta_1$ Gaps", R.L. Farrow, P.C. Black, and R.K. Chang, Proceedings of the International Conference on Lattice Dynamics, 1977, M. Balkanski, ed. (Flammarion Sciences, Paris, 1978), p. 182.

3. "Interaction of E_1 and $E_1 + \Delta_1$ Exciton Recombination with LO Phonons in III-V Semiconductors", R.L. Farrow and R.K. Chang, Solid-State Electron. 21, 1347 (1978).

4. "Interference of E_1 and $E_1 + \Delta_1$ Hot Exciton Luminescence with LO Phonon Raman Scattering in III-V Semiconductors", R.L. Farrow, R.K. Chang, and R.M. Martin, Physics of Semiconductors, 1978, B. L. H. Wilson, ed. (Institute of Physics, London, 1979), p. 485.

ELECTRONIC MATERIALS

NR 243-004, University of Southern California, "Gallium Nitride Growth", P.I.- Professor Murray Gershenzon, N00014-75-C-0095

This work is directed toward the growth and characterization of microwave grade gallium nitride substances and epitaxial films for eventual application to solid state high power amplifiers. Progress: Gallium nitride material has been grown up to thicknesses of 1 cm. Intrinsic donor conductivity of approximately 1 part in 10^{18}/cm^3 results from native defects at 34 mev. By photoluminescence and band edge absorption measurements, the energy levels of many donors and acceptors have been determined in GaN. Among those determined shallow donors are silicon, germanium, and native. The deep donors are carbon, oxygen, and sulfur. Shallow acceptors are zinc, germanium, and cadmium. Deep acceptors are beryllium and magnesium. Germanium, of course, is amphoteric.

Recent Publications:

1. Progress Report - April 1975 - "Evaluation of Gallium Nitride for Active Microwave Devices", M. Gershenzon

2. Progress Report - March 1976 - "Evaluation of Gallium Nitride for Active Microwave Devices", M. Gershenzon

3. Annual Progress Report - August 1977 - "Evaluation of GaN for Active Microwave Devices", M. Gershenzon, AD A045419

4. Annual Progress Report - October 1979 - "Evaluation of GaN for Active Microwave Devices", M. Gershenzon

NR 243-006, North Carolina State University, "Monte Carlo Predictions for Supervelocity Semiconductors", P.I. - Professor M. A. Littlejohn, N00014-76-C-0430

This work seeks to bypass the expensive and time consuming method of synthesizing new semiconductor materials to determine their properties and applicability to electronic devices. Instead, predictions of the charge transport characteristics are predicted (by Monte Carlo computer simulation) from known material properties and band structure. When fundamental properties are not precisely known, estimates are derived from materials of similar structure and ± confidence ranges are attached to the results. Progress: Monte Carlo methods and computer programs have been derived to simulate not only the high field low mobility transport conditions, but the low field, higher mobility conditions as well. The programs have been calibrated (tested) against experimental results for such materials as Ge, Si, GaAs, and InP. Predictions have been made for various mole fraction ratios of GaInAs, InAsP, and GaInAsP.

Recent Publications:

1. M. A. Littlejohn, J. R. Hauser, T. H. Glisson, D. K. Ferry, and J. W. Harrison, "Alloy Scattering and High Field Transport in Ternary and Quaternary III-V Semiconductors", Solid-State Electronics, Vol. 21, Pages 107-114, Jan 1978.

2. T. H. Glisson, J. R. Hauser, M. A. Littlejohn, and C.K. Williams, "Energy Bandgap and Lattice Constant Contours of III-V Quaternary Alloys", J. of Electronic Materials, Vol. 7, pages 1-16, Jan 1978.

3. M. A. Littlejohn, R. A. Sadler, T. H. Glisson, and J. R. Hauser, "Carrier Compensation and Alloy Scattering in $Ga_{1-x}In_xP_{1-y}As_y$ Grown by Liquid Phase Epitaxy" Inst. Phys. Conf. Ser. No. 45: Chapter 3, 1979.

4. "Influence of Central Valley Effective Mass and Alloy Scattering on Transient Drift Velocity in $Ga_{1-x}In_xP_{1-y}As_y$", M. A. Littlejohn, L. A. Arledge, T. H. Glisson, and J. R. Hauser, Electronics Letters, 13 Sep 1979, Vol. 15, No. 19, pages 586-588.

5. "Annual Report, "A Theoretical Search for Super-Velocity Semiconductors", by M. A. Littlejohn, J. R. Hauser and T. H. Glisson, dated 24 January 1979.

NR 243-015, Colorado State University, "Dielectric Layers on III-V Semiconductors", P.I. - James R. Sites, (303) 491-5850, N00014-76-C-0976

The objective of this program is to investigate dielectric layers, particularly those deposited by ion beam sputtering, for three specific applications: (1) MIS structures on GaAs, (2) encapsulation of GaAs for annealing purposes, and (3) electronic profiling of InAs layers. Progress: Progress in the past year focused on encapsulation of GaAs using silicon nitride and aluminum nitride. Targets of silicon and aluminum were sputtered with a beam of nitrogen or argon/nitrogen. Deposited layers 1000Å thick were screened for mechanical stability, index of refraction, and electrical breakdown when annealed at temperatures up to 935°C. More sensitive testing was achieved through the photoluminescence (PL) of the underlying GaAs. Changes in the PL spectrum were indicative of arsenic loss. With care, these changes could be eliminated for annealing temperatures up to 800°C in the case of AlN and 900°C for Si_3N_4 encapsulation. In the MIS area, Larry Meiners examined the frequency dependence of capacitance measurements to show conclusively that the fermi level at the surface was limited to a range from 0.7 to 1.1 eV below the conduction band minimum for a variety of dielectric coverings. Additionally, MIS studies of n-InAs with a SiO_2 insulator showed a separation of the accumulation layer electrons into three subbands and an electron mass enhancement as much as a factor of three.

Recent Publications:

1. "Silicon Nitride Layers on Gallium Arsenide by Low Energy Ion Beam Sputtering", L. E. Bradley and J. R. Sites, J. Vac. Sci. Technol. 16, 189 (1979).

2. "Electronic Profile of n-InAs on Semi-Insulating GaAs", H. A. Washburn, J. R. Sites and H. H. Wieder, J. Appl. Phys. 50, 4872 (1979).

3. "Dielectric-Semiconductor Interfaces of GaAs and InP," L. G. Meiners, Ph.D. Thesis, Colorado State University, 1979.

4. "Ion-Beam Sputtered AlO_xN_y Encapsulating Films", H. Birey, S. Pak, J. R. Sites and J. F. Wager, J. Vac. Sci. Technol. 16, (1979).

5. "Radiative Transitions Induced in Gallium Arsenide by Modest Heat Treatment", H. Birey and J. R. Sites, J. Appl. Phys., in press.

6. "Photoluminescence of Gallium Arsenide Encapsulated with Aluminum Nitride and Silicon Nitride", H. Birey and J. R. Sites, Appl. Phys. Lett. 35, 623 (1979).

NR 243-017, University of Illinois, "Quaternary Semiconductor Materials to Meet More Demanding Military Solid State Requirements", P.I. - Professor N. Holonyak, Jr. and Professor G. E. Stillman, (217) 333-4149, N00014-77-C-0086

This work seeks viable means of heteroepitaxially growing III-V quaternary semiconductor films on binary III-V substrates. LPE and VPE growth techniques are being investigated. Progress: The growth of $In_{1-x}Ga_xP_{1-z}As_z$-InP quaternary alloys by LPE and VPE is being studied. These materials are fabricated into heterostructure lasers and detectors. By means of LPE carried out in a computer-controlled cylindrical slider boat, multiple quantum-well quaternary heterostructure lasers have been grown with as many as 20 coupled quaternary active layers of thickness $L_z \lesssim 160$ Å. A quantum-well heterostructure with a small number of uncoupled quaternary active layers, by collecting holes but not electrons, has been used to measure the valence-band discontinuity ΔE_v (and thus $\Delta E_c = \Delta E_g - \Delta E_v \sim 2\Delta E_v$) between InP and InGaPAs. Photopumped LPE quaternary quantum-well heterostructures have operated as lasers on phonon sidebands below the lowest confined-particle states and have, in addition, operated CW at 300K. Long wavelength laser diodes of lesser temperature sensitivity, as already demonstrated for quantum-well $Al_xGa_{1-x}As$-GaAs lasers, should result from this work. The influence of various LPE growth techniques on the composition of the epitaxial layer (i.e., on the lattice constant and bandgap) has been studied and it has been shown that the step-cooling technique with growth at a constant temperature can be used for the growth of relatively thick constant composition epitaxial layers. The AsH_3-PH_3-Ga-In-H_2-HCl vapor phase quaternary growth system has been used to grow GaAs and InP homoepitaxial layers, and the influence of III/V ratio and gas flow rates on purity and growth rate have been studied in detail in preparation for VPE growth of quaternary heterostructures.

Recent Publications:

1. "Determination of the Valence-Band Discontinuity of InP-$In_{1-x}Ga_xP_{1-z}As_z$ ($x \sim 0.13$, $z \sim 0.29$) by Quantum-Well Luminescence", R. Chin, N. Holonyak, Jr., S. W. Kirchoefer, R. M. Kolbas, and E. A. Rezek, Appl. Phys. Lett. 34, 862-864 (1979).

2. "Phonon-Assisted Recombination in a Multiple Quantum-Well LPE InP-$In_{1-x}Ga_xP_{1-z}As_z$ Heterostructure Laser", E. A. Rezek, R. Chin, N. Holonyak, Jr., S. W. Kirchoefer, and R. M. Kolbas, Appl. Phys. Lett. 35, 45-47 (1979).

3. "Quantum-Well InP-$In_{1-x}Ga_xP_{1-z}As_z$ Heterostructure Lasers Grown by Liquid Phase Epitaxy (LPE)", E. A. Rezek, R. Chin, N. Holonyak, Jr., S. W. Kirchoefer, and R. M. Kolbas, J. Electronic Materials, to be published.

4. "Temperature Dependence of Threshold Current for Quantum-Well $Al_xGa_{1-x}As$-GaAs Heterostructure Laser Diodes", R. Chin, N. Holonyak, Jr., B. A. Vojak, K. Hess, R. D. Dupuis, and P. D. Dapkus, Appl. Phys. Lett. 36, to be published (Jan 1, 1980).

5. "The Influence of LPE Growth Techniques on the Alloy Composition of InGaAsP", M. Feng, L. W. Cook, M. M. Tashima, T. H. Windhorn, and G. E. Stillman, Appl Phys. Lett. 34, 392 (1979).

6. "The Vapor Phase Growth on InP Using the PH_3-HCl-In-H_2 Hydride Technique", L. W. Yinkiewicz, T. J. Lepkowski, and G. E. Stillman, Abstract 50-A, Los Angeles Meeting of the Electrochemical Society, October, 1979.

NR 243-018, RCA Laboratories "Semi-Insulating Gallium Arsenide Buffers for Military Microwave Devices", P.I.-Y. S. Narayan, N00014-77-C-0542

This work seeks techniques to reliably grow undoped GaAs layers of high resistivity (e.g., > 10^5-cm) for improved microwave solid state devices. Progress: Both the arsenic trichloride and the arsine approaches have been used to grow buffer layers. The arsenic trichloride approach appears to yield the most reproducable results. By using a solid boron nitride substrate holder, thermal uniformity is much improved resulting in a thickness uniformity of $\pm$ 2 over 95% of wafer center. This is especially noteworthy in increasing yield on GaAs integrated circuits. Completed in FY79.

Recent Publications:

1. Progress Report #1, "High Energy Ion Implantation for Multigigabit Rate GaAs Integrated Circuits", May 15 to July 15, 1978.

2. Semi-Annual Report for 1 July - 31 December 1977 "Epitaxial Growth of Semi-Insulating GaAs", S. T. Jolly, and D. Yaney.

3. Semi-Annual Report for period 1 July - 31 December 1977 dated March 1978 by S.T. Jolly, D. S. Yaney, and S. Y. Narayan", Epitaxial Growth of Semi-Insulating GaAs".

4. Technical Report for the period 7/77 - 6/78 "Epitaxial Growth of Semi-Insulating GaAs".

5. Interim Report, "Epitaxial Growth of Semi-Insulating GaAs", 7/78 - 3/79.

NR 243-021, Washington University in St. Louis, "Epitaxial Growth of $CdSnP_2$ on InP for Microwave FETs", C. M. Wolfe, (314) 889-6149, N00014-77-C-0664

The II-IV-V_2 chalcopyrite, $CdSnP_2$, appears to be an attractive material for high-speed device applications. The objective of this work is to develop this ternary compound into a technologically-useful material. For this purpose we are investigating the MBE and LPE growth of $CdSnP_2$ on InP substrates, the transport properties of the material, and the appropriate device fabrication technology. Progress: Epitaxial layers have been grown by both MBE and LPE, although the layers grown by MBE were of poor quality because of low substrate temperature. Ohmic contacts and Schottky barriers of good quality have been obtained. Resistivity and Hall measurements on encapsulated samples have been made up to about the melting point of the material.

Recent Publications:

1. Annual Technical Report for 1 Aug 77 - 31 Jul 78 dated 12 Dec 1978.

2. "Compound Semiconductors", J. Electrochem. Soc. 125, 487C (1978).

NR 243-022, Advanced Research and Applications Corporation, "Improvement in GaAs Device Yield and Performance Through Substrate Defect Gettering", P.I.-Dr. T. J. Magee, (408) 733-7780, N00014-78-C-0065

The objective of the present research program is to investigate and compare back surface damage techniques in regard to defect and impurity gettering in an attempt to optimize procedures that will be effective for improving the quality and performance of GaAs FET devices. Progress: During this period, we have used rotary abrasive back surface damage techniques to produce effective reductions in defect densities at the front surface of GaAs wafers. In addition, it has been shown that the back surface damage region rapidly getters mobile Cr in the wafer at temperatures of 740° to 750° C. Epitaxial layers grown on pre-gettered substrates exhibit a reduced microstructural defect concentration and lower levels of Cr outdiffused from the substrate. Significant improvements in FET structures fabricated in VPE layers on pre-gettered substrates have also been noted. These include: (1) a relative reduction in noise figure, (2) higher values of interface mobility, (3) lower epilayer/substrate effective resistance, and (4) an apparent increase in device yield/wafer.

Recent Publications:

1. "Back Surface Gettering and Cr Outdiffusion in VPE GaAs Layers", T. J. Magee, J. Peng, J. D. Hong, C. A. Evans, Jr., V. R. Deline and R. M. Malbon, Appl. Phys. Lett. 35 (1979).

2. "Alloying of Au Layers and Redistribution of Cr in GaAs", T. J. Magee, J. Peng, J. D. Hong, V. R. Deline and C. A. Evans, Jr., Appl. Phys. Lett. 35, 615-617 (1979).

3. "Gettering of Cr in GaAs by Back Surface Mechanical Damage", T. J. Magee, J. Peng, J. D. Hong, C. A. Evans, Jr., and V. R. Deline, Phys. Stat. Solidi(A), September 1979.

4. "Back Surface Gettering of Au in GaAs," T. J. Magee, J. Peng, J. D. Hong, and C. A. Evans, Jr., Phys. Stat. Solidi(A), September 1979.

NR 243-023, Westinghouse Research Laboratory, "InP Technology Base", P.I.-P. J. Oakes, N00014-78-C-0254

This work seeks to investigate techniques, processes, and designs for evaluating the usefulness of InP as a semiconductor material for microwave power FETs. Progress: Epitaxial InP Microwave FETs have been demonstrated in both P-N junction and Schottky gate versions.

Recent Publications:

1. "Indium Phosphide for High Frequency Power Transistors", 3/78 - 3/79, dated 19 October 1979.

NR 243-024, NRL, "Monolithic Microwave Power Subsystem Technology Base Support", P.I. - L. Whicker, N00014-78-WR-80152

This work provides basic support in GaAs materials technology and in integrated monolithic microwave circuit design to NR 251-029 at Westinghouse. Progress: Power FET modeling and characterization techniques have been developed and tested. Westinghouse FETs have been compared to others and deficiencies pointed out to Westinghouse.

Recent Publications:

1. Quarterly Report, 1/78 - 4/78.

2. Quarterly Report, 11/78 - 5/79.

3. Quarterly Report, 5/79 - 8/79.

NR 243-025, Hughes Research Laboratories, "Solution Growth and Laser Processing of GaAs Materials", P.I.- D. Pinnow, N00014-78-C-0337

This work seeks to investigate new (solution growth) techniques for insulating GaAs bulk semiconductor material and (2) laser processing techniques for the fabrication of microwave devices in GaAs. The solution growth technique is similar to that used for the growth of synthetic quartz. Below bandgap, near bandgap, and above bandgap laser frequencies will be used in both the C.W. and in the pulsed modes to activate impurity ions implanted into the GaAs. Completed in FY79. Progress: Solution growth of GaAs has been shown to be feasible although boules of a size large enough for practical use were not achieved. Laser annealing of ohmic contacts in GaAs devices was shown to be efficacious.

Recent Publications:

1. "GaAs Microwave Field Effect Transistors with Laser-Annealed Ohmic Contacts", G. Eckhardt, C. L. Anderson, L. D. Hess, N. Hirsch, and C. F. Krumm, dated 3/79.

2. "Ga Implantation into Si+ at Ultra-High Dose Rates", R. L. Kubena, R. R. Hart, H. L. Dunlap, M. D. Clark, V. Wang, R. A. Jullen, C. L. Anderson, and R. L. Seliger, to be presented at DRC in Boulder, CO, June 1979.

3. "Laser-Annealed Si and Se Implants for GaAs Microwave Devices", C. L. Anderson, H. L. Dunlap, L. D. Hess, and K. V. Vaidyanathan, to be published in Proceedings of the Symposium on Laser-Solid Interactions and Laser Processing, November 28 - December 1, 1979, Boston, MA.

4. Abstract "Overview of Ohmic-Contact Formation on Compound Semiconductors by Laser and Electron-Beam Annealing", by Gisela Eckhardt, dated 8/79.

5. Abstract "Annealing of Implanted Layers in Compound Semiconductors by Localized Beam Heating Techniques", by C. L. Anderson, H. L. Dunlap, L. D. Hess, R. A. McFarlane, G. L. Olson and K. V. Vaidyanathan, dated 8/79.

NR 243-026, Stanford University, "Preparation and Characterization of Single Crystals and Epitaxial Layers of Silicon Carbide by Molten Salt Electrolysis", P. I. - R. G. Feigelson, (415) 497-4007, N00014-78-C-0489

This work seeks a new approach to the growth of single crystal β-SiC, involving electrodeposition from a solution containing Si- and C-containing compounds in a molten salt solvent. Progress: The synthesis of silicon carbide by electrolysis of molten salts has been achieved for the first time, from two systems: K_2SiF_6 and Li_2CO_3 in KF/LiF eutectic, and Na_2CO_3 and SiO_2 in $NaBO_3$/LiF. The latter has given the more reproducible results, yielding polycrystalline SiC in the 2H and 33R polytypes.

Recent Publications:

1. "Conditions for Stable Growth of Epitaxial GaP Layers by Molten Salt Electrodeposition", R. C. DeMattei, D. Elwell, and R. S. Feigelson, J. Crystal Growth 44, 545 (1978).

NR 243-027, North Carolina State University, "Silicon Carbide Epitaxy for Electronic Devices", Robert F. Davis, (919) 737-3272, N00014-79-C-0121

There is considerable contemporary interest to develop wide bandgap single crystal semiconductor materials for employment in electronic devices in severe environments and for the development of blue light emitting diodes. Beta SiC is a primary candidate material as a solution of this problem area. As such, the principal objective of the present research program is the fabrication of β-SiC thin films of maximum crystallographic quality via the double-pronged routes of chemical vapor deposition and reactive sputtering. Structural, microstructural, chemical and electronic characterization of the resulting materials is an additional extremely important objective in this interative type program. In the coming year, chemical vapor deposition of Si and C resulting from the pyrolysis of methane and silane and reactive sputtering of a silicon target in the presence of methane or ethane will be conducted using (100) and (111) silicon and other types of substrates. The equipment and supplies for these experiments is now arriving and being assembled. Progress: New

NR 243-028, Cornell University, "Ballistic Transport in GaAs", P.I.-Professor L. Eastman, N00014-79-C-0290

This work seeks to verify the existance of reduced electron scattering in GaAs at low temperatures. Progress: Ballistic (non-scattering) transport of electrons was observed in submicrometer paths in GaAs material cooled to 77°K and below.

Recent Publications:

None

NR SRO-004, Washington University, "Millimeter Wave Technology", P.I. - Professor F. Rosenbaum, N00014-79-C-0840

This work seeks both the improvement of present III-V semiconductors and devices and the synthesis of new materials and devices for improved performance in millimeter wave sources, amplifiers, and detectors. Progress: Self-generated electric fields present during the growth of III-V compounds have been found to greatly influence the character of the resulting material.

Recent Publications:

None

NR SRO-005, California Institute of Technology, "Low-Loss Flexible Dielectric Wave-

guide for Millimeter Waves", P.I. - Professor W. Bridges, N00014-79-C-0839

A process has recently been developed for extruding various well-known IR materials, such as KRS-5 (thallium bromoiodide), in long fibers. The transmission line loss of unclad samples, measured at 35 and 94 GHz, was about 1/10 that of conventional rectangular guide. The objectives of this project are to investigate the electromagnetic properties of these extruded dielectrics as flexible, low-loss mm-wavelength transmission lines and study various circuit realizations using these lines. The contractor will (a) measure the characteristics of these materials in various configurations, investigate and develop various core cladding materials, and determine mode characteristics, phase behavior, etc., of transmission lines at 30-300 GHz; (b) extend and develop theory to cover rectangular clad waveguide for the practical cases of large differences in core cladding dielectric constants and cladding of wavelength thickness; and (c) investigate experimentally and analytically various components in this medium, specifically, transitions to waveguide, directional couplers, mixer circuits, etc. Progress: new

Recent Publications:

None

SOLID STATE ELECTRONICS

NR 373-009, University of Hawaii, "Charge Transport and Applications in FET Subbanding Systems", P. I. - James W. Holm-Kennedy, (808) 948-7249, N00014-76-C-1081

The semiconductor interface is a complex system affected by a host of physical processes. The role of the interface physics in electronic devices performance is major. Our research effort addresses the problems of the interface in a novel way. The effort here is to evolve new electronic devices which are model sensitive to the interface physics and to use these devices as diagnostic probes of the interface physics. Simultaneously, the effort is to evolve new and useful electronic devices. Emphasis is on FET subbanding systems. Progress: The development of one of these proposed devices has been completed and the basic electronic character for basic electronic character for which it was designed has been ovserved in devices fabricated in our laboratory. Numerous such devices have been fabricated. Additional related technology development has been initiated. Optical and charge transport studies have been performed on these devices and are on going at the University of Hawaii. Devices have also been supplied to colleagues elsewhere for collaboration on similar studies.

Recent Publications: None.

NR 373-010, Rockwell International Corporation, "Study of Heterojunction Discontinuities in Semiconductors", P. I. - Dr. E. A. Kraut/Dr. R. W. Grant, (805) 498-4545, N00014-76-C-1109

The energy gap discontinuity ΔEg in a heterojunction is distributed between the valence and conduction bands on each side of a heterojunction interface so that $\Delta Eg = \Delta Ev + \Delta Ec$. ΔEv and ΔEc represent the valence and conduction band portions of the discontinuity ΔEg, respectively. Our objective is to determine ΔEv and properties which influence its magnitude by using a new application of x-ray photoelectron spectroscopy (XPS) on heterojunctions grown by molecular beam epitaxy (MBE) in-situ withing an HP 5950A XPS spectrometer. By fitting the edge of an experimental XPS valence band spectrum with an instrumentally broadened theoretical valence band density of states it is possible to measure, precisely, the energy of the valence band edge relative to an XPS core level such as the Ga 3d core level in GaAs or the Ge 3d core level in Ge. Given this information and an independent measurement of the core level splitting between the Ga 3d core levels across a thin (~20Å) Ge/GaAs heterojunction interface, it is possible to deduce directly the valence band discontinuity ΔEy. Progress: The energy of the GaAs valence band edge relative to the Ga 3d core level has been determined to be 18.81 ± 0.02 eV and the energy of Ge valence band edge relative to the Ge 3d core level has been determined to be 29.55 + 0.02 eV. These values give ΔEy = 0153 ± 0.02 eV when combined with our measured 10.21 ± 0.01 eV core level splitting between the Ge 3d and Ga 3d core l[illegible]s in a thin Ge-GaAs (110) abrupt heterojunction. A preliminary analysis of AlAs [illegible] data shows the valence band edge of AlAs to be 40.30 ± 0.08 eV above the [illegible] level. The first direct experimental results which demonstrate that no ge[illegible]al transitive relation exists for heterojunction band discontinuities have been obtained. By using XPS the (110) nonpolar abrupt heterojunctions in the series Ge/CuBr, CuBr/GaAs, and GaAs/Ge have been found to exhibit a large deviation from transitivity. The sum of the valence band discontinuities for these junctions is 0.64 eV, a large deviation from the zero sum expected by transitivity.

Recent Publications:

Grant, R. W., Waldrop, J. R., and Kraut, E. A., "Observation of the Orientation Dependence of Interface Dipole Energies in Ge-GaAs", Phys. Review Letters 40, 9 (1978).

Grant, R. W., Waldrop, J. R., and Kraut, E. A., "XPS Measurements of Abrupt Ge-GaAs Heterojunction Interfaces", J. Vac. Sci. Technol. 15, 1451 (1978).

Harrison, W. A., Kraut, E. A., Waldrop, J. R., and Grant, R. W., "Polar Heterojunction Interfaces", Physical Review B18, 4402 (1978).

NR 373-022, North Carolina State University, Raleigh, NC, "The Correlation of Second Phase and Defect Structures with the Electrical Properties of Ion Implanted III-V Compounds", P. I. - Prof. R. B. Benson, N00014-75-C-0827

This program utilized advanced transmission electron microscopy (TEM) and Secondary Ion Mass Spectroscopy (SIMS) techniques to study ion implantation into III-V compound semiconductors. The goals of this work are to identify the types and nature of crystalline defects which arise in ion-implanted III-V compounds, either prior to or following thermal and laser annealing, and to correlate these defects with observed electrical and optical properties. Initial work has concentrated on GaAs material and specific p- and n-type implanted species. For example, Be and Se have been extensively studied, with additional work on Zn, Mg, Cd, Si, and Te having been undertaken. At the present time the work has been extended to include other important compound semiconductors such as InP and the epitaxial material systems GaAlAs/-GaAs and GaInAs/InP. Progress: For gallium arsenide annealed after implantation with Be the atomic Be concentration and defect density profiles were compared as a function of fluence. The atomic concentration profiles were determined by secondary ion mass spectrometry (SIMS) and the defect profiles by transmission electron microscopy (TEM) techniques. The characteristics of unfaulted dislocation loops in GaAs annealed after implantation with Be were determined using TEM techniques. The loop chaaracteristics were consistent with the loops being aggregates of matrix interstitials. Preliminary observations revealed that the large drop in electrical activity in GaAs annealed after implantation when the Be fluence increases from 1×10^{15} to 5×10^{15} ions/cm^2 may be associated with the formation of a new defect at the higher fluence level. For GaAs annealed at 850^{o}C after implantation with a Se fluence of 5×10^{13} ions/cm^2 at various implantation temperatures, a relationship was established between the atomic Se distribution and the distribution of unfaulted dislocation loops.

Recent Publications:

"Some Structural and Electrical Characteristics of GaAs Annealed After Implantation With Be, Mg, Zn, and Cd", R. B. Benson, M. A. Littlejohn, K. S. Lee, and R. E. Ricker, Ion Implantation in Semiconductors and Other Materials, Ed. F. Chernow, p. 131, Plenum Press, NY, 1977.

"A Relationship Between Be Concentration Profiles and Defect Density Profiles in GaAs Annealed After Implantation With Be", K. S. Lee, J. M. Ess, M. A. Littlejohn, R. B. Benson, and J. Comas, to be published in the Journal of Electronic Materials.

"Analysis of Unfaulted Dislocation Loops in GaAs Annealed After Ion Implantation With Be", R. E. Ricker, K. S. Lee, J. Comas, R. B. Benson, and M. A. Littlejohn, to be published in the Journal of the Electrochemical Society

NR 373-024, United Technologies Research Center, "Physics of Small, Hot Electron Semiconductor Devices," P. I. - Dr. H. L. Grubin, (203) 727-7026, N00014-78-C-0269

The direction of semiconductor research toward smaller device size and high frequency operation involves the use of high mobility compound semiconductors such as gallium arsenide, indium phosphide, and other binary, ternary and quaternary materials. Common to most of these semiconductors is the property of negative differential mobility (NDM) whose most dramatic manifestation is the presence of spontaneous oscillations arising from propagating space charge layers. It is known that NDM is size dependent and devices shorter than 0.1 microns possess either weak or no NDM. Under the present contract the transient and size dependence of NDM semiconductor two and three terminal devices are examined. The study involves solving Poisson's equation, the continuity and circuit equations, and equations describing the device. For device with active region lengths, $L > 1$ micron the device equations include specific relations between velocity, diffusion and electric field. For $0.1 < L < 1$ micron, the device is described by the first three moments of the Boltzmann transport equation using the displaced Maxwellian approximation. Present features under study are: (i) $L > 1$ micron, contact effects, doping variations, substrates, charge injection, gate oxides in FET's hole conduction, circuit effects; (ii) $0.1 < L < 1$ micron, contact and circuit effects, doping, size and space charge dependence. Progress: GaAs FET's with gate lengths between 1 and 2 microns have been separated into two groups according to the ratio, R, of their curoff and saturation voltages. Those with $R > L$ were shown, theoretically, to exhibit NDM originated spontaneous oscillations. Those with $R \approx 1$ were electrically stable. In collaboration with others and using state-of-the-art GaAs FET's these predictions have been experimentally confirmed. The switching properties of GaAs FET's with $R \approx 1$ were examined and compared to silicon FET switches. For comparable device dimensions and doping levels GaAs was faster, approximately, by the ratio of their mobilities. By scaling down the silicon dimensions and increasing its doping, silicon FET's were found to have switching properties similar to that of GaAs. For devices with $0.1 < L < 1$ microns the size dependence of NDM was explicitly calculated. NDM was shown to disappear in GaAs when $L \approx 0.1$ micron. In addition, satellite valley transient relaxation was examined. It was determined that satellite valley differential repopulation can lead to velocity 'overshoot' effects.

Recent Publications:

" Spontaneous Oscillations in Gallium Arsenide Field Effect Transistors", H. L. Grubin, D. K. Ferry, and K. R. Gleason, Solid State Electronics (in press)

"Hot Electron Induced Oscillations in Gallium Arsenide Field Effect Transistors", H. L. Grubin, D. K. Ferry, and K. R. Gleason, Conference Record of the 3rd Biennial University/Industry/Government Microelectronics Symposium

"Transient Relaxation Effects in Transferred Electron Devices", H. L. Grubin, D. K. Ferry, J. R. Barker, M. A. Littlejohn, T. H. Gleason and J. R. Hauser, Proc. 7th Cornell Conference on Active Mocrowave Devices and Circuits (in press)

"Hot Electron Contributions in Two and Three Terminal Semiconductor Devices", H. L. Grubin, NATO Advanced Study Institute Seminar Notes (in press)

"The Gunn-Hilsum Effect", M. P. Shaw, H. L. Grubin and P. R. Solomon, Academic Press New York (1979)

NR 373-030, Oregon State University, "Heterojunctions in Semiconductors", P. I. - Professor S. J. T. Owen, N00014-77-C-0608

Ge/GaAs heterojunctions grown by various techniques are being studied, both experimentally and theoretically to elucidate current transport mechanisms within the device and their relationship with junction parameters, such as doping level, thickness, interface and bulk traps, and composition. Progress: Semiconductor heterojunctions have been fabricated by growth of p-type Ge onto n-type GaAs substrates by liquid phase epitaxial growth of Ge from Pb-Sn and Ga melts. These heterojunctions have been examined by x-ray diffraction, Auger profiling spectroscopy and electrical characterization. Transient capacitance, double-source differentiated photo-capacitance and deep level transient spectroscopy techniques have been established to investigate these and other devices. In order to characterize our systems, and to gain experience on measurements on simpler device structures, i.e., Schottky barriers, our initial experiments have been on organo-metallic vapour-phase GaAs, and liquid epitaxial $Al_xGa_{1-x}As$ and $In_xGa_{1-x}As\ P_{1-y}$. Theoretical studies of tunneling effects in semiconductor heterojunctions have established some of the effects of heavy doping on junction behavior. Future work will concentrate on extending the capacitance techniques to heterojunctions grown here and in other laboratories, and in correlating these measurements with theoretical studies of current transport mechanisms with particular emphasis on tunneling.

Recent Publications:

"Investigations of Deep Trap Levels in Organometallic Vapor Phase Epitaxial Gallium Arsenide", P. K. Bhattacharya, J. W. Ku, S. J. T. Owen, V. Aebi, B. Cooper III, and R. L. Moon, Government/Industry/University Microelectronic Symposium, Lubbock, TX May 1979. (Submitted for publication in Applied Physics Letters).

"Investigation of Non-Radiative and Radiative Deep-Level Centers in $Al_xGa_{1-x}As$", P. K. Bhattacharya, S. J. T. Owen and J. Marrs, European Solid State Device Research Conference, Munich, W. Germany, September 1979. (Submitted for publication in Applied Physics Letters).

"Evidence of Trapping in Device Quality Liquid Phase Epitaxial $In_{1-x}Ga_xAs_yP_{1-y}$", P. K. Bhattacharya, J. W. Ku, S. J. T. Owen, S. H. Chiao and R. Yeats (Accepted for publication in Electronic Letters).

NR 373-034, University of Wisconsin-Madison, "Excited State Properties of Semiconductor Electrodes and Their Application to Optical Energy Conversion", P. I. - Arthur B. Ellis, (608) 262-0421, N00014-78-C-0633

The use of luminescent semiconductor electrodes to probe aspects of interfacial charge transfer in photoelectrochemical cells will be investigated. Emission provides a tool with which to characterize excited state deactivation processes. In particular, the competition between radiative and nonradiative decay as a function of experimental parameters can be examined. The n-type semiconductors CdS:Te andCdS:Ag emit at room temperature while they serve as electrodes in photoelectrochemical cells. Comparisons between their emissive properties for excited states generated electrochemically in strongly oxidizing media (electroluminescence) and photochemically (photoluminescence) will be explored. The quenching of emission by both interfacial electron and

energy transfer will be examined. Systems which exhibit multiple emission bands (highly doped CdS:Te, for example) will be studied from the standpoint of assessing communication among the several excited states. Both quenching and lifetime studies will be used to quantify the excited state deactivation processes. Progress: The emissive properties of CdS:Te and CdS:Ag electrodes in photoelectrochemical cells employing polychalcogenide electrolyte have been determined. Emission spectral distribution is independent of the presence and composition of polychalcogenide electrolyte, excitation wavelength (457.9-514.5 nm) and potential (-0.3 V vs. SCE to the onset of cathodic current). The emission intensity for intraband gap excitation (λ < 500nm) is potential dependent, varying inversely with photocurrent. Increased temperature improves band gap edge photocurrent and quenches emission intensity. These observations have been interpreted in terms of optical penetration depth and the band bending model of photoelectrochemical phenomena.

Recent Publications:

"Luminescent Properties of Semiconductor Electrodes", A. B. Ellis and B. R. Karas, Division of Colloid and Surface Chemistry, Abstract #65, 176th Meeting of the American Chemical Society, Miami Beach, 1978.

"Luminescent Photoelectrochemical Cells: Use of Tellurium-Doped Cadmium Sulfide Photoelectrodes to Probe Surface Recombination During the Conversion of Optical Energy to Electricity", A. B. Ellis and B. R. Karas, J. Amer, Chem. Soc., 101, 236 (1979)

"Luminescent Properties of Semiconductor Photoelectrodes". A. B. Ellis and B. R. Karas, Adv. Chem. Ser., in press

"Luminescent Photoelectrochemical Cells. 2. Doped Cadmium Sulfide Photoelectrodes as Probes of Excited State Processes Which Influence Optical to Electrical Energy Conversion", B. R. Karas and A. B. Ellis, J. Amer. Chem. Soc., in press.

"Thermal Manipulation of Deactivation Processes in Luminescent Photoelectrochemical Cells Employing Tellurium-Doped Cadmium Sulfide Photoelectrodes", B. R. Karas, D. J. Morano, D. K. Bilich, and A. B. Ellis, J. Electrochem, Soc., submitted for publication.

NR 373-035, Polytechnic Institute of New York, "Defects and Surfaces", P. I. - Prof. Daniel C. Mattis, (212) 643-2448, N00014-78-C-0594

This work concerns several applications of theoretical physics to electronic, optical and materials properties of solids especially near surfaces, e.g. deviation from stoichiometry. Progress: We have been able to solve for the properties of excitons near surfaces in 2 distinct models. The recombination processes, mainly of the internal Auger type, have not yet been worked out as this involves a 3- or 4-body problem which is insoluble except in weak-coupling. However, we have recently developed a scheme denoted "tridiagonalization" which renders this type problem amenable to nonperturbative solution by a systematic numerical analysis and decomposition into "hyperpartial waves". It is intended to apply this method as soon as the programming packages are developed, to study the electronhole recombination mechanisms. An application of our recent molecularfield theory, we have obtained equations for a binary ally near a surface or for the equivalent Ising magnet. In its most simplified form this theory includes corrections to the usual Landau-Ginzburg equation:

$$-m''(z) = m(t-m)+H$$

where $t=T_c-T$, H= applied field, z= distance from surface, and " indicates second derivative. The equation includes the new parameter D (which is O(1) in these units):

$$-m''(z)-Dm(m')^2 = m(t-m) +H$$

which is quite relevant at low temperature ($t\sim1$) but becomes irrelevant in the critical region ($t\sim0$). Also, our study has given a new meaning to the "extrapolation length" λ, allowing it to be related to the physical parameters of the surface.

Recent Publications:

"Eigenstates of Excitons Near a Surface", D. ,attis and G. Beni, Phys. Rev. B18, 3816 (1978)

"Green's Theorem Calculation of Exciton..." J. Gallardo and D. Mattis, Phys. Stat. Sol. (b) 93, 229 (1979)

"Molecular Field Theory with Correlations", D. Mattis, P. R. B19, 4737 (1979)

"Order Parameter Near Surfaces of Solids", J. Gallardo and D. Mattis, to be published.

NR 373-038, Brooklyn College of CUNY, "High Sensitivity Optical Modulated Optical and Ramon Investigation of GaAs and its Oxides", P. I. - Dr. Fred H. Pollak, (212) 780-5356, N00014-78-C-0718

The nature of the surfaces in the preparation of semiconductor devices has been a concern of long standing. In particular the increasingly important role played by GaAs in the fabrication of semiconductor devices suggest the need for a fundamental understanding of its surfaces. Recently, considerable interest has been shown toward oxidation from the viewpoint of application to surface passivation, planar technology and fabrication of MOS field effect transistors. However, the basic oxidation process in GaAs has only recently been studied from a fundamental point of view. Progress. Using a high sensitivity rotating light-pipe reflectometer, we have studied the anodization and dissolution process for GaAs oxide films in situ using a tartaric acid/glycol/water electrolyte. Different stages in the oxidation-dissolution process can be easily identified, and the film thickness can be calibrated interferometrically in situ. In conjunction with this study, we have investigated the electrolyte electroreflectance spectra of GaAs in the vicinity of the E_0 transition (direct gap at k = 0), and have observed a pronounced excitonic feature which is very sensitive to surface fields. We have identified this effect as a type of interference phenomenom within the semiconductor depletion region. This feature and the observed Franz-Keldys oscillations are thus used to optically study the surface electric fields and interface states, with and without an oxide layer.

Recent Publications:

"Optical Studies of Anodic Oxide Films on GaAs Using a Rotating Hight-Pipe Reflectometer", R. P. Silberstein and F. H. Pollak, to be published.

"Optical and Modulated Optical Investigation of the Semiconductor-Oxide-Electrolyte Interface in GaAs", R. P. Silberstein and F. H. Pollak, to be published in Surface Science.

Observation of Exciton Quenching in GaAs at Room Temperature Using Electrolyte Electroreflectance", R. P. Silberstein and F. H. Pollak, to be published in Solid State Comm.

"Investigation of the Semiconductor-Oxide-Electrolyte Interface in GaAs Utilizing Electrolyte Electroreflectance", R. P. Silberstein and F. H. Pollak, to be published in the Journal of Vacuum Science and Technology.

NR 373-039, State University of New York at Albany, "Semiconductor Surfaces and Semiconductor-Electrolyte Interfaces", P. I. - Professor Walter M. Gibson, N00014-78-C-0616

Surfaces and interfaces of semiconductors have been of central importance to electronics applications since the invention of the transistor. Indeed, the properties and stability of integrated circuits are often determined by surface and interface reactions and structures both during processing and in the final electronic device. As such devices become smaller and more complex, control of surfaces becomes even more important. The surface studies under ONR sponsorship is designed to address primarily the question: "Where are the surface atoms?". Such information is needed to supplement the extensive surface symmetry, compositional and electronic and chemical information gathered by LEED, Auger, Appearence Potential Spectroscopy Photoelectron Emission and ESCA studies. The tools employed are Mev ion scattering to determine the structure of clean silicon surfaces and the structure of the interface between silicon and adsorbed layers and Standing Wave X-rays to determine positions of adsorbed atoms at the silicon-electrolyte and at the silicon-silicon oxide interface. Both of these techniques are relatively new, in fact this program represents the first systematic application of the Standing-Wave X-ray technique to surface studies. The ion beam measurements are carried out in an Ultra High Vacuum Chamber, connected to the 4.5 Mev Dynamitron Accelerator with a turbomolecular pumped differential pumping chamber. In addition to ion scattering, Medium Energy Electron Diffraction (MEED) and Auger Electron Spectroscopy (AES) measurements are also made. The x-ray technique utilizies a standing wave x-ray field resulting from interference between a Bragg scattered x-ray beam and an incident monoenergetic, collimated x-ray beam. The sensitivity (less than 1/4 monolayer) and accuracy (~.02Å) of the measurement are very high. Furthermore, the penetrating power of the x-ray used allow interface impurities (even at liquid-solid interfaces) to be studied. Progress: The ion beam scattering apparatus is fully operational and extensive measurements have been made to clean silicon 100 and hydrogen adsorbed 100 surfaces. Saturated atomic hydrogen coverage (2 atoms of H for each surface Si atom) results in complete relaxation of reconstruction in the plane of the surface. Extensive contraction normal to the surface still remains, however, with at least two monolayers relaxed more than 0.3Å. Four monolayers of silicon appear to be involved in the surface contraction. Computer simulation of the experiment for differenct channeling directions and ion energies shows promise for completed understanding of the clean and H adsorbed Si (100) surface. Preliminary measurements of oxygen covered and gold covered Si (100) surfaces have been made. The oxygen results show a reduced but persistent reconstruction and the gold results indicate a dramatic threshold in silicide formation as a function of gold coverage at about four monolayers at room temperature. The electronic computer system for the x-ray measurements is undergoing final assembly and testing. In the meantime, manual measurements at SUNYA and measurements on a similar set up at Bell Laboratories have shown a strong correlation between the lattice and the position of adsorbed bromine.

Recent Publications:

"Hydrogen Adsorption of Si (100) Surfaces", T. Narusawa and W. M. Gibson, reported at 26th Annual Symposium of American Vacuum Society, New York, October 5, 1979, to be published in Surface Science.

NR 373-040, Rockwell International/Electronics Research Center, Anaheim, CA, "Electronic Transport in Ultra-Thin Heterostructures", P. I. - P. D. Dapkus, N00014-78-C-0711

As the dimensions of semiconductor devices become smaller and smaller, the effects due to the small dimensions being employed are of greater importance, both for their effect on the performance of conventional devices as well as for their utilization in the fabrication of new devices with expanded capabilities. The physics of quasi-two-dimensional solids represents the limit of reducing the thickness of the device to quantum dimensions. A model system which provides the opportunity to study these effects is the GaAlAs/GaAs heterostructure system. Here the GaAs is sandwiched between two layers of GaAlAs in such a way that the GaAs is essentially a quasi-two-dimensional solid. This system is of interest not only as a model system, but because of its technological importance. There are three aspects to the study of these quasi-two-dimensional solids being approached in this program:

(1) Transport measurements of multi-layer GaAlAs/GaAs material with quantum well dimensions are being pursued;

(2) Photoluminescence evaluation of ultra-thin GaAlAs/GaAs quantum well samples are being examined from very low levels of excitation to excitations sufficient for photo-excited laser operation;

(3) The utilization of these multiple quantum well structures in the fabrication of new devices with expanded capabilities are being studied.

This program will identify the scattering mechanisms operative in the transport along two-dimensional quantum well channels by the utilization of Hall and other standard transport measurements. It will also identify the radiative transitions operative in quantum well GaAlAs/GaAs materials. It further will explore methods utilizing these properties in the fabrication of prototype devices with expanded capabilities. Progress: The luminescence of quantum well GaAlAs/GaAs materials has been studied in detail. It has been found that the energy of the luminescence is dominated by the quantized energy levels within the GaAs quantum well and that in these layered structures enhanced electron phonon coupling occurs owing to the reduced symmetry of the material. These effects have been utilized in the fabrication of GaAlAs/GaAs quantum well lasers with multi-layer active regions. These devices exhibit exceedingly low laser thresholds with differential quantum efficiencies on the order of 85%. Furthermore, the utilization of multiple quantum well active regions results in a reduced sensitivity of laser threshold to temperature variations of the device. As a result, the laser threshold can be expressed by the relationship $J(T) = J_0 \exp(+T/T_0)$, where T_0 is of the order of 240 to 450°K. These important observations are the result of the modification of the density of states in two-dimensional solids and the very strong electron phonon coupling occurring in ultra-thin solids

Recent Publication:

R. D. Dupuis, P. D. Dapkus, N. Holonyak, and R. M. Kolbas, Appl. Phys. Lett., 35, 487 (1979)

B. A. Vojak, N. Holonyak, Jr., R. Chin, E. A. Rezek, R. D. Dupuis, and P. D. Dapkus, J. Appl. Phys., 50, 5836 (1979)

B. A. Vojak, S. W. Kirchoefer, N. Holonyak, Jr., R. Chin, R. D. Dupuis, and P. D. Dapkus, J. Appl. Phys., 50, 5830 (1979)

R. D. Dupuis, P. D. Dapkus, R, M. Kolbas, and N. Holonyak, Jr., IEEE, JQE, QE15, 756 (1979)

R. M. Kolbas, N. Holonyak, Jr., B. A. Vojak, K. Hess, M. Alterelli, R. D. Dupuis, and P. D. Dapkus, Solid State Comm., 31, 1033 (1979)

N. Holonyak, Jr., R. M. Kolbas, W. D. Laidig, M. ALterelli, R. D. Dupuis, and P. D. Dapkus, Appl. Phys. Lett., 34, 502 (1979)

R. D. Dupuis, P. D. Dapkus, C. M. Garner, C. Y. Su, and W. E. Spicer, Appl. Phys. Lett., 34, 335 (1979)

R. D. Dupuis, P. D. Dapkus, R. Chin, N. Holonyak, Jr., S. W. Kirchoefer, Appl. Phys. Lett., 34, 265 (1979)

NR 373-041, University of Illinois, "Mechanisms for Secondary Ion Production in Sputtering", P. I. - Dr. Peter Williams, (217) 333-0386, N00014-78-C-0621

The physical mechanisms underlying the production of secondary ions by sputtering are investigated; particular attention is given to processes relevant to the analytical uses of secondary ion emission. The studies involve the effects of sputtering and primary ion implantation on the microstructural and electronic properties of the sputtered surface, and of the influence of the altered surface on sputtered ion yields. Concurrently, an ultra-high vacuum system has been constructed in which we hope to produce well-characterized surfaces which model practical sputtered surfaces, and evaluated their ion emitting properties. Current attention is focussed on the cascade mixing process initiated by primary ion bombardment and the effects of this mixing on surface chemistry and ion yields after sputtering through an interface. Progress: The influence of the substrate sputter yield on the surface concentration of the primary species has been investigated for a wide variety of elemental substrates. The results generally confirm earlier findings that the sputter yield is the factor dominantly controlling primary species concentration, and therefore ion yield. Ion yields corrected for these sputter-yield related matrix effects scale in a simple way with ionization potential or electron affinity for all elements studied, which indicated that the ion emission problem can be conveniently subdivided into surface effects and free atom effects. Absolute yields of sputtered ions and excited atoms have been compared under closely comparable conditions. Ion yields are found to be an order of magnitude higher than excited atom yields on oxygenated surfaces; this finding can be rationalized by considering level-crossing processes as the sputtered atom leaves the surface if potential energy surfaces appropriate to the surface (rather than the gas phase) are constructed. The cascade mixing process has been investigated for the case where the sputtering front crosses an interface. The sputter yield of the overlayer species has been shown to be reduced in the substrate

by up to two orders of magnitude because much of the overlayer material becomes buried by cascade mixing beyond the sputtered atom escape depth. The results also show that the extent of cascade mixing in silicon depends on the nature of the impurity species.

Recent Publications:

"Parameters Influencing Ionization Efficiencies in Secondary Ion Mass Spectrometry", W. Katz, Thesis, University of Illinois, 1979.

"The Sputtering Process and Sputtered Ion Emission", P. William, Surface Science, in press.

"Towards a Unified Model for Sputtered Ion Emission", P. William, W. Katz, and C. A. Evans, Jr. Proc. 4th Int. Conf. on Ion Beam Analysis, Aarhus 1979, Nucl. Instr. and Meth., in press.

"A Comparison of Absolute Yields of Excited Neutrals and Positive Ions from Ion-Bombarded Surfaces", P. William, I. S. T. Tsong, and S. Tsuji, Proc. 8th Int. Conf. on Atomic Collisions in Solids, Hamilton 1979, Nucl. Instr. and Mehtods, in press.

NR 373-045, The Research Foundation of the State University of New York, Stony Brook, New York, "LEED Structure Analysis of GaAs(111) and GaAs($\bar{1}\bar{1}\bar{1}$)", P. I. - F. Jona, (516) 246-7649, N00014-79-C-0504

Calculations are made for a quantitative analysis of LEED intensity data from GaAs (111)2x2 and GaAs($\bar{1}\bar{1}\bar{1}$)2x2 with dynamical diffraction procedures. Large sets of experimental data have been collected by Dr. B. Mrstik (NRL). The research involves postulation of suitable models, computer calculations of expected LEED intensities and objective (r-factor) evaluation of all models. Solution of these structural problems is expected to have notable impact on the understanding of the relationship between atomic reconstruction and electronic properties of semiconductor surfaces. Progress: New.

NR 373-065, Cornell University, "Growth and Physics of III-V Semiconductor Alloy and Heterojunction Structures for Improved Microwave Devices by LPE and MBE", P. I - Professor Lester F. Eastman, (607) 256-4369, N00014-75-C-0739

The limitations of electron transport in the bulk of compound semiconductor devices, including electron mobility, high-field saturated velocity, ballistic velocity in short devices, and the confinement of electrons to thin channels require alternative materials and geometries for improved microwave performance at higher frequency. The optimization of LPE and MBE growth proceedures, and the determination of physical and electronic properties, of III-V alloy semiconductors and their interfaces with compound semiconductors, are sought for improved microwave devices. $Al_xGa_{1-x}As/GaAs$ heterojunctions, grown by both LPE and MBE are being pursued to obtain improved, confined electron transport in the GaAs. $InP/In_xGa_{1-x}As$ heterojunctions grown by both LPE and MBE are also being pursued to obtain more improvement of electron transport in the $In_xGa_{1-x}As$, confined by the heterojunction with InP. Auger analysis of the heterojunctions and the physics of heteroepitaxy are also being pursued. In order to

have reproduceable lattice match for the MBE $In_xGa_{1-x}As$ on InP, a special combined In and Ga source cell has been developed and will be used. Rectification across the $In_xGa_{1-x}As$/InP heterojunction will be sought and studied as a function of operating temperature. Progress: High purity[4] $Al_xGa_{1-x}As$/GaAs abrupt heterojunctions grown by LPE with donor concentration in the $Al_xGa_{1-x}As$ less than $1x10^{15}/cm^3$ and with the composition change at the heterojunction in less than 100 Å, have given repeatable rectification for the first time. The LPE $Al_xGa_{1-x}As$ is pure enough to allow the determination of alloy scattering from low temperature mobility measurements for the first time. The LPE $In_xGa_{1-x}As$ purity has also been improved to a new state-of-the-art, yielding 13,800 cm^2/V-s and 70,000 cm^2/V-s mobility at 300°K and 77°K, and donor density of $3.5x10^{14}/cm^3$. Extrapolation of the 77°K mobility to a case with no ion scattering allows the determination of the alloy scattering mobility to be 85,000-90,000 cm^2/V-s at that temperature. Initial experiments on $In_xGa_{1-x}As_yP_{1-y}$ quaternary showed that its mobility is always less than that of $In_xGa_{1-x}As$, contrary to Monte Carlo theory. The room temperature mobility of $In_xGa_{1-x}As$ has yielded 40-50% higher values than those of GaAs for the same donor concentration.

Recent Publications:

"Rectification at n-n GaAs: (Ga,Al)As Heterojunctions", A. Chandra, and L. F. Eastman, Electronics Letters, 15, pp. 90-91 (February 1979).

"A Study of Alloy Scattering in $Ga_{1-x}Al_xAs$", A. Chandra and L. F. Eastman, Journal of Applied Physics, (January 1980).

"A Study of the Conduction Properties of a Rectifying nGaAsn(Ga, Al)As Heterojunction", A. Chandra and L. F. Eastman, to be published in Solid State Electronics.

"The Liquid Phase Epitaxial Growth of High Purity $Ga_{1-x}Al_xAs$", A. Chandra and L. F. Eastman, Journal of the Electrochemical Society, (January 1980).

NR 373-104, University of Minnesota, "Insulating Films on Gallium Arsenide", P. I. - Professor G. Y. Robinson, (612) 373-3026 , N00014-76-C-0579

This project is an experimental investigation of the formation and the electrical characteristics of thin insulating layers on the compound semiconductor gallium arsenide, GaAs. The primary objective of the study is to obtain fundamental knowledge of the insulator-semiconductor interface for thin-film structures formed by two different methods: (1) growth of oxide layers by plasma anodization, and (2) chemical vapor deposition of silicon nitride layers by a low temperature plasma-enhanced technique and a high temperature pyrolytic process. The plasma anodized films are analyzed by in-situ Auger spectroscopy and low energy electron loss measurements. Electrical measurements of the insulating film and interfaces using the MOS C-V technique indicate the interface state density. Secondary ion mass spectrometry is used to determine oxide growth kinetics. Progress: Thin oxide films of Ga-As-O have been grown by anodization of GaAs in the negative glow region of a dc oxygen discharge. It was found that interstitial oxygen motion was not the dominant mass transport mechanism and the surface of the film is Ga-rich during growth. Majority carrier trapping occurred in the oxide and the interface state density exhibited a minimum of $3x10^{12}cm^{-2}eV^{-1}$ in lower half of the band gap. An overlayer of anodic Al_2O_3 did not reduce the density of interface states nor substantially alter the Ga-As-O oxide composition. Si-N films formed by r.f. plasma deposition and by pyrolytic CVD were also studied. The bulk dielectric properties were superior to the anodic oxides, but the interface state energy distributions were similar to the oxide/GaAs case.

Recent Publications:

"DC Plasma Anodization of GaAs", L. A. Chesler and G. Y. Robinson, App. Phys. Lett., 32, 60 (1978).

"Auger Analysis of Anodic Oxide and CVD Nitride Films on Gallium Arsenide", G. Y. Robinson, paper at the International Conference on Solid Films and Surfaces, Tokyo, Japan, July 1978.

"Plasma Anodization of GaAs in DC Discharge", L. A. Chesler and G. Y. Robinson, J. Vac. Sci. Technol., 15, 1525, (July/Aug. 1978); Conference on the Physics of Compound Semiconductor Interfaces, USC, Jan. 1978.

"Electrical Properties of Plasma-Deposited Si-N Films on GaAs", T. R. Ohnstein, G. Y. Robinson, M. J. Helix, B. G. Streetman, and K. V. Vaidyanathan, paper WP-A4, Device Research Conference, Boulder, CO, June 1979.

NR 373-262, California Institute of Technology, "Semiconductor Devices and Phenomena", P. I. - Professor A. Yariv, (213) 795-6841, N00014-76-C-0322

The research is concerned with new optical devices and lasers which are based on seimiconductor materials and microfabrication processes and their monolithic integration with high speed electronic components. In parallel, we are pursuing theoretical and experimental studies on carrier dynamics in GaAs/GaAlAs and of laser self pulsations. Both the GaAs material system and GaInAsP are grown epitaxially in the laboratory. Progress: The first examples of monolithic integration of semiconductor GaAs/GaAlAs lasers with microwave devices have been demonstrated. These include Laser-Gunn diode, Laser-FET amplifier. Semi-insulating GaAs was shown to be a suitable substrate for monolithic integration. Laser alloying of ohmic contacts on GaAs devices was found to lead to lower contact resistance. We have obtained preliminary theoretical results correlating pulsation of injection lasers with material and optical parameters. Investigations will be made on the feasibility of increased integration such as detector-amplifier-laser devices. We will measure and characterize the frequency modulation response of the laser and laser/FET integrated circuit and explore a number of new semiconductor lasers based on semi-insulating substrates. We will proceed with theoretical and experimental analysis of laser pulsation and modulation and theory of current flow in composite heterojunctions under high injection conditions.

Recent Publications:

"Guided Wave Optics", Amnon Yariv, Scientific American, Vol. 240, 63-72, January (1979).

"Transverse Bragg-Reflector Injection Lasers", J. B. Shellan, W. Ng, P. Yeh, A. Yariv, and A. Cho, Optics Letters, Vol. 2, 136-138, May (1978).

"Integration of an Injection Laser with a Gunn Oscillator on a Semi-Insulating GaAs Substrate", C. P. Lee, S. Margalit, I. Ury, and A. Yariv, Appl, Physics Letters, Vol. 32, 806-807, June 15 (1978).

"Q-Switched Ruby Laser Alloying of Ohmic Contacts on Gallium Arsenide Epilayers", Shlomo Margalit, Dan Fekete, David M. Pepper, Chien-Ping Lee, and Amnon Yariv, Appl. Physics Letters, Vol. 33, 346-347, August 15 (1978).

"GaAs-GaAlAs Heterostructure Lasers on Semi-Insulating Substrates", Chien-Ping Lee, Shlomo Margalit, and Amnon Yariv, IEEE Trans. on Electron Devices, Vol.ED-25, 1250-1256, October (1978).

"Monolithic Integration of an Injection Laser and a Metal Semiconductor Field Effect Transistor", I. Ury, S. Margalit, M. Yust, and A. Yariv, Appl. Physics Letters, Vol. 34, 430-431, April (1979).

NR 373-615, University of California, Berkeley, "Millimeter Wave Maser Amplifiers", P. I. - C. Townes, N00014-76-C-0070

This study is directed toward the development of travelling wave types of masers, with particular emphasis given to amplifying regions which have broad band dispersive structures. Design, tunability, sensitivity, and phase stability of masers operating in the 3 to 20 millimeter wavelength region are being investigated. Work is directed towards decreasing size and complexity and increasing performance and serviceability. Superconducting slow-wave structures are being investigated to obtain lower losses and hence high gain, lower pump power, and shorter wavelength. Masers will be designed for use with continuously operating refrigerators. Progress: Successful reduction in system noise to very low figures by maser amplifiers has permitted measurements on interstellar and galactic sources not previously practical, i.e. provided more sensitivity and shorter observing times. There has now been considerable experience in operating 1.0-1.5 cm amplifiers on the microwave antennas and interferometer at the Hat Creek Observatory of the University of California and on the 85 foot antenna of the Naval Research Laboratory. The initial maser systems have been improved in tunability and bandwidth. System noise temperatures in the range 70-150 K are generally obtained; these are now largely dominated by radiation from the atmosphere and warm waveguides. Phase stability of the maser amplifiers has been shown to be rather goo, allowing their use in interferometry. This has produced interferometric maps of interstellar molecular emission which were not otherwise practical.

Recent Publications:

"An Upper Limit to the Interstellar Abundance of the HCN Dimer", J. W. V. Storey and A. C. Cheung, Astrophys. Lett. Vol. 19, 87 (1978)

"An Interferometric and Multi-transitional Study of the Orion Methanol Masers", Dissertation, University of California, Berkeley, Demetrios Nicholas Matsakis, December, 1978.

RADIATION AND SOLIDS

NR 322-004, State University of New York, Albany, NY, "Defects in Semiconductors", P. I. - Professor J. W. Corbett, (518) 457-8315, N00014-75-C-0919

Studies of defects in semiconductors, defects produced by diffusion, by heat-treatment, by electrolysis, by ion implantation of foreign species are of great importance to a broad spectrum of Navy electronics systems. Radiation-effect studies support nuclear radiation vulnerability programs and ion implantation studies support new material and electron device technology. The central issue is to identify the defects induced in silicon and determine their properties, their production and annealing mechanisms. Silicon is of technological interest but is also the model system. A study of diamond in collaboration with G.E. and of III-V compounds with NRL is being carried out. These programs seek to identify the radiation and impurity induced defects in semiconductors by EPR, capacitance, optical, channeling, back-scattering, positron annihilation, and electrical measurements in silicon, diamond, and gallium arsenide. Correlative theoretical studies on defect properties, and defect-production, -diffusion, and -reaction mechansisms will be carried out. Progress: DLTS and EPR measurements have shown Fe to be a common impurity in silicon; continuing studies of the role and gettering of transition elements is being carried on. Experimental and theoretical studies of the states of hydrogen in silicon have been carried out, and continue. Theoretical work on impurities (He, Li, Be, e^+, etc.) in silicon are being carried out as are comparable studies in GaAs and GaP. EPR and ENDOR measurements on dislocations in silicon continue. The role of defects generated by laser damage and annealing continue, as do studies of a junction as a sink for damage.

Recent Publications:

"Les Defauts Ponctuels dans les Semiconducteurs", J. C. Bourgoin and J. W. Corbett, J. de Phys., colloque c2, supplement au no. 6, tome 39, Juin 1978, pp. C17-21.

"Survey of Defects", Proc. NATO Advanced Study Institute, 1978, Albany, NY

"Radiation Damage, Defects and Surfaces", Surface Science, in press

"Photodegradation in Silicon", J. W. Corbett, A. Jaworowski, R. L. Kleinhenz, C. B. Pierce and N. D. Wilsey, to be published.

"Defects in Silicon", J. W. Corbett, A. Jaworowski, J. P. Karins, R. L. Kleinhenz, J. L. Lindstrom, P. M. Mooney, G. Oehrlein, L. M. Roth, Vijay A. Singh, K. L. Wang, E. Weber and N. D. Wilsey in "Radiation Physics of Semiconductors and Related Materials", ed. G. P. Kekelidze (University of Tbilisi Press, Tbilisi, 1980) in press.

"The Effect of Spatial Correlation on Steady State Nucleation of Voids", (with D. Peak) Rad. Eff. 36 197-203 (1978)

"Calculations on the Properties of Helium in Silicon", (with D. R. Kaplan and C. Weigel), Phys. Stat. Solidi, in press.

"Semi-Empirical Calculations of Hydrogen Defects in Silicon" (with Vijay A. Singh, C. Weigel and L. M. Roth) Phys. Letters, 65A, 261-63 (1978)

"Realistic Renormalization Group Calculations of Defects in Solids" (with C. Weigel and S. T. Chui) Phys. Rev. B 18, 2377-86 (1978)

"ENDOR of a Dislocation Center in Deformed Silicon" (with V. A. Grazhulis, C. P. Scholes), Phys. Lett. 66A, 398-400 (1978).

"Defects in Laser Damaged Silicon Observed by DLTS" (with P. M. Mooney, R. T. Young, J. P. Karins, and Y. H. Lee), Phys. Stat. Sol. (a) 48, K31-34 (1978).

"Defect Distribution Near the Surface of Electron-Irradiated Silicon" (with K. L. Wang and Y. H. Lee), Applied Phys. Letters 33, 547-8 (1978).

"High Temperature Ion Implantation in Diamond" (with Y. H. Lee and P. R. Brosious) Phys. Stat. Sol. (a) 50, 237-242 (1978).

"Infrared Absorption of Silicon Irradiated by Protons" (with N. N. Gerasimenko, M. Rolle, L. J. Cheng, Y. H. Lee and J. C. Corelli) Phys. Stat. Sol. B90, 689-696 (1979).

"Positron Lifetimes in GaAs" (with L. J. Cheng, J. P. Karins and L. C. Kimerling) J. Appl, Phys. 50, 2962-2964 (1979).

"EPR Studies on Quenched-In Defects in Silicon" (with Y. H. Lee and R. L. Kleinhenz) in press.

"Studies of the States of Hydrogen in Silicon" (with R. L. Kleinhenz, Y. H. Lee, Vijay A. Singh, P. M. Mooney, A. Jaworowski, L. M. Roth and J. C. Corelli) in press.

"New Optical Method for Studying Defects in Silicon" (with M. T. Mitchell and J. C. Corelli) in press.

"Radiation-Induced Defects in Czochralski Grown Aluminum-Doped Silicon" (with P. M. Mooney, K. L. Wang, A. Jaworowski and Y. H. Lee) to be published.

"A DLTS Study of Radiation-Induced Defects in Aluminum-Doped Silicon" (with Y. H. Lee, K. L. Wang, A. Jaworowski, P. M. Mooney and L. J. Cheng) to be published.

NR 322-041, California Institue of Technology, "Study of Semiconductor Structures", P. I. - Professor J. W. Mayer, (213) 795-6811, N00014-75-C-0564

The performance of integrated circuits is determined to a large extent by the outer layers of the structures; oxide metallization layers as well as dopant distributions are important. One of the areas studied is the reaction of metals and silicon to form silicide layers. The other primary area is the growth of epitaxial layers of silicon and germanium from amorphous films formed by ion implantation or vacuum deposition. The general objectives of the study were to characterize the factors which influence silicide formation and epitaxial growth under various processing conditions as furnace annealing, laser or electron-beam transient annealing and ion-beam-induced reactions. Rutherford backscattering spectrometry with MeV ^{4}He ions and transmission electron microscopy were the main analytical tools used. Progress: Silicide Formation. Radioactive and silicon tracers were used to investigate the growth of $CrSi_2$ and Pd_2Si and PtSi. We concluded that Si is supplied directly from the silicon substrate as well as from the silicide layers. In other studies, we utilized a thin, deposited Pt film as a marker in the formation of nickel silicide. This showed that the formation and growth of NiSi occurs by decomposition of Ni_2Si at the Ni_2Si-NiSi interface. We initiated a program to study the reactions induced by energetic ions penetrating through metal-semiconductor interfaces. We found for Ni, Pd and Pt films that the first phase formed was

M_2Si and that the thickness was proportional to (ion dose)1/2. Epitaxial Growth. The primary emphasis was on the use of transient annealing, pulsed ($\simeq 10^{-7}$ sec duration) laser and electron beams to grow epitaxial layers. We found that high quality layers could be formed from both implanted-amorphous and deposited amorphous layers. We propose that such growth required that the incident power be sufficient to melt the amorphous layer at the crystal interface; at lower powers, the layer is polycrystalline. It was also possible to grow epitaxial Ge layers on Si substrates.

NR 322-047, Stanford University, "Studies of Surfaces and Interfaces on 3-5 Compounds", P. I. - W. E. Spicer , (415) 497-4643, N00014-75-C-0289

Because of their direct band gap and low electron mass, 3-5 semiconductors have a wide range of potential uses in the Navy, e.g. FET's optical communications, and fast IC's. A principle barrier to such utilization is the difficulty in optimizing the interfaces between the semiconductor and 1) its own "natural oxide" (this is present in all practical devices; however, it is often kept as thin as possible and covered with a second passivation layer such as SiO_2 or Si_2N_3) or 2) a metal (e.g. a Schottky Barrier), or a 3-5 of different composition (i.e. a heterojunction). The strategy has been to use the unique capabilities of synchrotron radiation available from the Stanford Synchrotron Radiation Laboratory (SSRL) to produce photoemission from the last few atomic layers of the semiconductor. The photoemission spectroscopy (PES) is used to examine the valence bands, surface states, and core levels. The free surface is first studied then oxygen or metal atoms are placed on the surface in a very controlled manner and the chemical and metallurgical interactions studied and correlated with changes in the electrical properties. Results from these studies are correlated with "real" devices studies. Sputter-Auger techniques are also used to study interfaces which lie many atomic or molecular layers below the surface. Progress: A new mechanism has been identified for Schottky barrier formation. This is the formation of vacancies in the 3-5 due to deposition of the metal. The same mechanism has also been found to apply to formation of defect levels at the semiconductor oxide interface; thus, allowing for the developing of a unified theory for b[illegible]h the Schottky barrier and oxide 3-5 interface. Detailed defect (the stable defec[illegible]ay be a defect complex rather than a simple vacancy) state assignments have been made in terms of energy, missing cation or anion, and donor or acceptor character for GaAs, InP, and GaSb. These results will provide detailed information as to the Schottky barrier height or interface states to be expected. Difference with various processing can be rationalized and suggestions for radically changing electric properties (e.g. Schottky Barrier Height) can be developed. Using sputter-Auger techniques heterojunction widths have been measured on GaAlAs: GaAs heterojunctions made by conventional vapor phase epitoxy (CVPE), organometallic vapor phase epitaxy (OMVPE), liquid phase epitaxy (LPE), and molecular beam epitaxy (MBE). The smallest widths for CVPE or LPE, about 80Å; OMVPE, about 12Å; and, about 5Å for MBE. These results are important in understanding and predicting device behavior and in demonstrating a new degree of depth resolution for sputter-Auger techniques.

Recent Publications:

"A New and Unified Model for Schottky Barrier and 3-5 Insulator Interface States Formation", W. E. Spicer, P. W. Chye, P. R. Skeath, C. Y. Su, and I. Lindau: accepted for publication in J. Vac. Sci. Technol. (1979)

"Nature of Interface States at III-V Insulator Interfaces", W. E. Spicer, P. W. Chye, P. R. Skeath, C. Y. Su, and I. Lindau, accepted by the Institute of Physics Conf. Series, No. 50: Insulating Films on Semiconductors (1979)

"Fundamental Studies of 3-5 Surfaces and the 3-5 Oxide Interface", W. E. Spicer, I. Lindau, P. Pianetta, P. W. Chye, C. M. Garner, Thin Solid Films 56, 1,2, pp. 1-18 (1979)

"Photoemission Study of Au Schottky-barrier Formation on GaSb, GaAs, and InP using Synchrotron Radiation", P. W. Chye, I. Lindau, P. Pianetta, C. M. Garner, C. Y. Su, and W. E. Spicer, Phys. ev. B, Vol. 18, No. 10, pp. 5545-5559

"The Surface Electronic Structure of 3-5 Compounds and the Mechanism of Fermi Level Pinning by Oxygen (Passivation) and Metals (Schottky Barriers)", W. E. Spicer, P. W. Chye, C, M. Garner, I. Lindau and P. Pianetta; Surface Science 86, pp. 763-788 (1979)

"Use of Photoemission and Related Techniques to Study Device Fabrication", W. E. Spicer, NonDestructive Evaluation of Semiconductor Materials and Devices, Chapter 8, (1979), Plenum Publishing Corp., edited by Jay N. Zemel

"Effect of GaAs or $Ga_xAl_{1-x}As$ Oxide Composition on Schottky-barrier Behavior", C. M. Garner, C. Y. Su, W. A. Saperstein, K. G. Jew, C. S. Lee, G. L. Pearson and W. E. Spicer, J. Appl, Phys. 50(5), May 1979

"Photoemission Study of the Interaction of Al with a GaAs(110) Surface", Perry Skeath, I. Lindau, P. Pianetta, P. W. Chye, C. Y. Su, and W. E. Spicer, Journal of Electron Spectroscopy and Related Phenomena, 17, pp. 259-265 (1979)

"Photoemission Studies of the Initial Stages of Oxidation of GaSb and InP", P. W. Chye, C. Y. Su, I. Lindau, C. M. Garner, P. Pianetta and W. E. Spicer; Surface Science 88, pp. 439-460 (1979)

"Oxygen Adsorption on Cs Covered GaAs(110) Surfaces", C. Y. Su, P. W. Chye, P. Pianetta, I. Lindau, and W. E. Spicer, Surface Science 86, pp. 894-899 (1979)

"Comparative Studies of Oxygen Adsorption on GaAs (110) Surfaces with Ultra-Thin Aluminum and esium Overlayers"; P. Skeath, C. Y. Su, P. W. Chye, P. Pianetta, I. Lindau, and W. Spicer; accepted for publication in J. Vac. Sci. Technol. March (1979)

"The Oxidation of Ordered and Disordered GaAs (110)", P. W. Chye, C. Y. Su, I. Lindau, P. Skeath, and W. E. Spicer, accepted for publication in J. Vac. Sci. Technol. (1979)

"The Surface Electronic Structure of GaAs (110): Effects of Wxygen and Metal Overlayers", I. Lindau and W. E. Spicer, Electron Spectroscopy, Volume 4, Academic Press Inc. (London) Ltd.

"Investigation of the Mechanism for Schottky Barrier Formation by Group 3 Metals on GaAs"; P. Skeath, I. Lindau, P. W. Chye, C. Y. Su, and W. E. Spicer, accepted for publication in J. Vac. Sci. Technol. (1979).

"Abrupt $Ga_{1-x}Al_xAs$-GaAs Quantum-well Heterostructures Grown by Metalorganic Chemical Vapor Deposition", R. D. Dupuis, P. D. Dapkus, C. M. Garner, C. Y. Su, W. E. Spicer, Appl, Phys, Lett. 34, (5), pp. 335-337, 1 March 1979.

"Minimum $Al_{0.5}Ga_{0.5}As$-GaAs Heterojunction Width Determined by Sputter-Auger Techniques", C. M. Garner, C. Y. Su, W. E. Spicer, P. D. Elwood, D. Miller, J. S. Harris, Appl, Phys. Lett. 34(9), 1 May 1979

"Growth and Properties of Graded Band-Gap $Al_xGa_{1-x}As$ Layers", P. Kordos, R. A. Powell, W. E. Spicer, and G. L. Pearson, Appl. Phys. Lett. 34(6), 15 March 1979

"Interface Studies of $Al_xGa_{1-x}As$-GaAs Heterojunctions", C. M. Garner, C. Y. Su, Y. D. Shen, C. S. Lee, G. L. Pearson and W. E. Spicer, J. Appl. Phys. 50(5), May 1979

NR 322-050, Naval Research Laboratory, "Distribution of Ion Implanted Dopants in Semiconductors", P. I. - Dr. J. Comas, (202) 767-2146, N00014-79-WR-90028

This project has been mainly concerned with the distribution of implanted dopants in semiconductors, especially in Si, GaAs and InP. Our studies have shown that the depth distribution of ion implanted dopants in semiconductors often do not follow normal diffusion kinetics subsequent to annealing. Diffusion processes in ion-implanted crystalline substrates are a complex combination of material and dopant parameters such as defect production, dopant concentration, defect enhanced migration, diffusivity, and lattic reordering. Although the degree to which these phenomena contribute to the distributions are both dopant and substrate dependent and are not known in detail, it appears that many of the observations of anomalous diffusion result from mechanisms that are damage associated. Information on the dopant distribution bears directly on the application of implantation doping on semiconductors, especially when the requirements for reproducible, predictable, and controlled electrically active profiles are essential. Progress: Beryllium atomic concentration profiles obtained by SIMS have been compared with defect density profiles determined by TEM techniques. Be concentration profiles and defect density profiles both exhibited approximately similar distributions for each respective fluence (Be, 100, keV, $5x10^{13}cm^{-2}$, $1x10^{15}cm^{-2}$) in the region of the layer where the specimens were compared. The results suggest that the concentration of Be and its associated implantation induced damage are the major factors responsible for the significant redistribution of defects observed for the high and low implant fluence cases. Photoluminescence spectra from VPE GaAs implanted with overlapping distributions of Be acceptors and Se donors have been studied as a function of excitation intensity and temperature. The substrates were at room-temperature for the Be implants and 350°C for the Se implants, and were subsequently annealed at 800°C for 30 min. Donor-acceptor pair radiative recombination involving implanted acceptors and implanted donors was observed and provided direct evidence for the optical activation of implanted donors in GaAs. Limitations on the control of dopant distributions resulting from implantation into single-crystal silicon due to ion channeling were examined for a range of ion atomic numbers and energies characteristic of semiconductor device fabrication. The results of this study indicated that to minimize the extent of unintentional channeling, alignment of the ion beam to the nearest low-index crystallographic direction must be at angles exceeding twice the critical angle and that the angle required can exceed the commonly used seven degree tilt angle especially for ions of large atomic number at low energy.

NR 322-053, Naval Research Laboratory, "Defects in Semiconductors", P. I. - Dr. A. Hemstreet, (202) 767-3414, N00014-79-WR-90028

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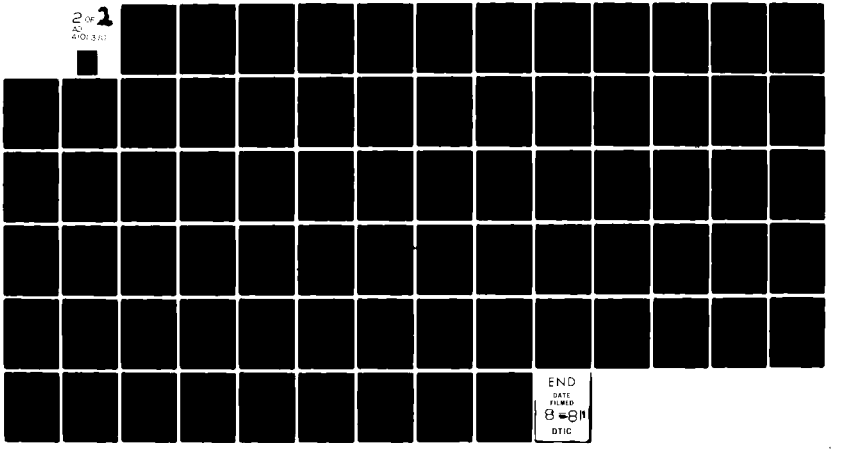

Defects which produce energy levels deep within the bandgap of a host semiconductor often play a dominant role in determining the electronic properties of the material. However, until recently, the strongly localized nature of the defect perturbation, which makes the usual effective-mass-like theories inapplicable has impeded a theoretical understanding of the properties of such deep level defects. In the cluster approach one takes advantage of the importance of these short range interactions and focuses attention only on a "Molecule" composed of the defect under consideration and a relatively small number of neighboring host atoms (generally less than fifty). In the present investigations such clusters representing various lattic defects and/or transition metal impurities in semiconductors such as silicon, gallium arsenide, and indium phosphide are being considered, and realistic self-consistent calculations of the electronic states of such clusters are carried out using the $X\alpha$ scattered wave formalism. The defect properties are directly deduced by comparison of results from clusters both with and without the defect in question and are analyzed in terms of the local bonding properties of the defect-host system. Progress: Recent calculations have focused mainly on the transition metal impurities, chromium and iron, in gallium arsenide and indium phosphide. Within the single electron approximation, both impurities are found to produce two defect states within the host bandgap. These states have substantial d character and originate from the crystal-field-split atomic d states of the transition metal impurity. However, it was found to be necessary to go beyond the one electron approximation to correctly describe the spin of the defect ground state as well as the localized intra-center transitions so prominent in the experimental photoluminescence and adsorption spectra. Two methods of treating the electronic correlations between electrons associated with the defect levels have been investigated: a modified version of atomic multiplet theory, and a spin polarized cluster calculation, whereby electrons of differing spin are treated separately. While the latter approach sometimes exhibits convergence problems, both approaches appear to describe, at least qualitatively, the gross features associated with such strong electronic interactions. Currently, similar calculations are being extended to other transition metal impurities in GaAs and InP as well as to other semiconductor hosts such as GaP.

Recent Publications:

"Cluster Calculations of the Electronic States of Cr^{2+} in GaAs", L. A. Hemstreet and J. O. Dimmock, Solid State Communications, 31, pp 461-464 (1979).

"Electronic States of a Substitutional Chromium Impurity in GaAs", L. A. Hemstreet and J. O. Dimmock, Phys. Rev. B 20, pp 1527-1537 (1979)

NR 322-059, University of Illinois at Urbana-Champaign, "Ion Implantation Doping Studies in GaAs", P. I. - B. G. Streetman, (217) 333-6813, N00014-76-C-0806

This research explores properties of GaAs, with an emphasis on those properties most relevant to present and future electronic device requirements. Ion implantation, encapsulation, and annealing are studied, along with deep-level impurities and defects. Measurements include deep-level transient spectroscopy (DLTS), low-temperature photoluminescence, secondary ion mass spectrometry (SIMS), Auger electron spectroscopy (AES), and differential Hall effect profiling. Theoretical work includes effects of high fields on generation-recombination from deep levels, heterojunction properties, and hot electron effects. Progress: We have recently examined impurity and phonon scattering in layered structures, a modification of

DLTS for study of implanted material, and have proposed a new class of electronic devices employing real-space electron transfer between multilayer heterojunctions at high fields. We have also described an rf plasma-enhanced silicon nitride deposition system for encapsulating GaAs with an oxygen-free nitride for annealing. We have shown the importance of oxygen-free nitride encapsulation in preventing gallium outdiffusion, the effects on implanted GaAs p-n junctions, and applications to avalanche photodiodes.

Recent Publications:

"RF Plasma Deposition of Silicon Nitride Layers", M. J. Helix, K. V. Vaidyanathan, B. G. Streetman, H. B. Dietrich, and P. K. Chatterjee, Thin Solid Films, 55, 143-148 (1978).

"Planar Ion-Implanted Avalanche Photodiodes in GaAs", R. A. Milano, M. J. Helix, T. H. Windhorn, B. G. Streetman, K. V. Vaidyanathan, and G. E. Stillman, Gallium Arsenide and Related Compounds, Bristol: Inst. Phys. Conf. Ser. 45, 411-419 (1978).

"Negative Differential Resistance Through Real Space Electron Transfer", K. Hess, H. Morkoc, H. Shichijo, and B. G. Streetman, Appl, Phys. Lett., 35, 469-471 (1979).

"A New Version of Deep Level Transient Spectroscopy for Diodes with Large Leakage Currents", D. S. Day, M. S. Helix, K. Hess, and B. G. Streetman, Rev. Scient. Instrum., (1979).

"Impurity and Phonon Scattering in Layered Structures", K. Hess, Appl. Phys. Lett., 35, 484-486 (1979).

"Phonon-Assisted Recombination and Stimulated Emission in Multiple Quantum-Well MO-CVD AlGaAs-GaAs Heterostructures", R. M. Kolbas, N. Holonyak, B. A. Vojak, K. Hess, M. Altarelli, R. D. Dupuis and P. K. Dapkus, Solid State Communications, 31, 1033-1037 (1979).

NR 322-060, University of Massachusetts, Amherst, MA, "Deep Impurity States in Gallium Arsenide", P. I. - Claude M Penchina, (413) 545-3666, N00014-76-C-0890

As part of a long term program objective to study deep impurity levels in semiconductors, we have been studying chromium and oxygen impurity states in Gallium Arsenide. The immediate objective has been the identification and understanding of the optoelectronic properties of GaAs doped with these impurities. Additional experiments are planned, however, to investigate some isotope effects on zerophonon lines and vibronic sidebands. Progress: We have studied Cr and O in GaAs using a wide variety of techniques, including optical absorption, photoconductivity, cathodoluminescence, photo-Hall effect, photocapacitance, thermally stimulated current, and dark capacitance transients. One Cr luminescence band at 0.84eV was found to be due to a multiplet of internal transtions at the Cr impurity; a photoconductive band with similar threshold energy was found to be not simply related to these transitions, but to involve two-carrier transport and quenching effects. The second Cr liminescence band (.57 eV) was found to exhibit a Fano type resonance and a local phonon mode. Preliminary analysis indicated that it is due to a different charge state of Cr, which increases the nearest neighbor lattice interaction by 20% compared with the Ga it replaces. Oxygen was found to produce a broad lum-

inescence band which is quite sensitive to radiation damage. Photocapacitance, transient capacitance, and transient current measurements indicate it introduces several levels in the gap. A survey of many samples for use in our experiments indicated that undoped semi-insulating GaAs from the U.S. Naval Research Lab. (Swiggard et al) was unusually free of deep levels. However, doped GaAs (Cr,Te) from the same source showed a large number of medium-deep centers in the gap; presumably unintentional impurities are introduced as a result of the doping process.

Recent Publications:

"Effect of Proton Damage on Optical Modulation Spectra of Gallium Arsenide", M. Oren, A. R. Quinton, and C. M. Penchina, J. Electrochem Soc. 125, 776-81, (1978).

"Fine-Structure of Cathodoluminescence from Chromium Doped Gallium Arsenide", E. C. Lightowlers and C. M. Penchina, J. Phys. C. Letters 11,L405-9 (1978)

"Temperature Dependence of the Fine Structure in the Luminescence and Absorption Spectra of Chromium-Doped Gallium Arsenide", E. C. Lightowlers, M. O. Henry, and C. M. Penchina. Inst. Phys. Conf. Ser. 43, 307-10 (1979)

"Luminescence of Cr in GaAs", C. M. Penchina, in "New Developments in Semiconductor Physics" Springer (to be published)

"Luminescence of Cr in GaAs: Fano Resonance and Local Modes" C. M. Penchina, E. C. Lightowlers, M. O. Henry, M. Zavetova and B. Velicky, Proceedings of RECON 1979 (to be published)

"GaAs:Cr Luminescence and Photo-Transport" C. M. Penchina, R. Masut, E. C. Lightowlers, M. O. Henry, M. Zavetova and B. Velicky, Paper Presented at 2nd Lund. Int. Conf. on Deep Level Impurities in Semiconductors, Ste Maxime, France May 1979 (unpublished).

NR 322-061, National Bureau of Standards, "Structural Determination of Solid Surfaces", P. I. - Dr. D. T. Pierce, (301) 921-2051, N00014-78-F-0034

The geometrical atomic structure of metal and semiconductor surfaces and of thin overlayer materials is difficult to determine. It has been suggested that spin polarization effects in Low Energy Electron Diffraction (LEED) experiments could reduce the ambiguity in surface structure analysis and provide clarification to understanding the factors involved in the scattering processes. To utilize spin polarization in surface structure determination, the investigators have developed a unique, high current polarized electron gun and incorporated it into a LEED apparatus. Since the most complete spin average LEED structural determinations available are for metals, the first polarized LEED (PLEED) measurements have been of a metal surface, W(100), in order to make a comparison. In the coming year, measurements will be made of spin dependent scattering at surface resonances of W(100), and PLEED data will be obtained from a Au(111) crystal. In contrast to polarized electron scattering from W(100) where the spin dependence arises due to the spin orbit interaction, there is a spin dependence in scattering from a ferromagnetic surface due to the exchange interaction which is proportional to the

surface magnetization. Our measurements of the surface magnetization of Ni(110) will be extended to test for magnetically dead layers and investigate the role of magnetic electrons in chemisorptive bonding. Future work will include a comprehensive study of compound semiconductor surfaces, i.e., ideal, reconstructed, oxidized, and those covered with thin overlayers. Progress: The polarized electron gun, using photoemission from negative electron affinity GaAs(100), produces and electron beam polarization of 43% and a current of 20 μA for each μW of incident photon flux at 1.6 eV. An explanation was suggested for the lower polarization (21%) observed by others for GaAs(110). A symmetry principle in PLEED was established theoretically and experimentally in measurements of W(100). A complete set of data has been obtained for W(100) suitable for comparison to dynamical calculations. The first measurements of polarized electron scattering from a ferromagnetic surface were made on Ni(110). A surface hysteresis curve was obtained corresponding to the magnetization of the outer two atomic layers. The temperature dependence of the surface magnetization exhibited much less curvature than that of the bulk.

Recent Publications:

"Face Dependence of the Spin Polarization of Photoelectrons From NEA GaAs(100) and (110)", D. T. Pierce, G. -C. Wang, and R. J. Celotta, Appl, Phys. Lett. 35, 220-222 (1979).

"Symmetry in Low-Energy-Polarized-Electron Diffraction", G.-C.Wang, B. I. Dunlap, R. J. Celotta, and D. T. Pierce, Phys. Rev. Lett. 42, 1349-1352 (1979).

"Surface Magnetization of Ferromagnetic Ni(110): A Polarized LEED Experiment", R. J. Celotta, D. T. Pierce, G. -C. Wang, S. D. Bader and G. P. Felcher, Phys. Rev. Lett. 43, 728-731 (1979).

NR 322-062, Naval Research Laboratory, "Impurities in Materials", P. I. - Dr. J. J. Krebs, (202) 767-3603, N00014-79-WR-90428

Deep impurities in III-V compound semiconductors, particularly important for semi-insulating substrates of GaAs and InP, are still imperfectly understood. This Task studies transition-metal and oxygen dopants by EPR and photoluminescence (PL). It has already characterized two and tentatively identified a third charge state of Cr in GaAs and found two Cr PL bands. In InP only one Cr state has been found. Present models of Cr in GaAs cannot correlate specific states with the PL bands, locate the energies of the states in the forbidden gap, or account for complex optical fine structure observed by English workers. A combined EPR-PL technique will be used to correlate the EPR and PL centers. Samples will be prepared with controlled Fermi levels to define the charge states of Cr clearly and allow corrdinated characterization by transport and DLTS measurments. Oxygen is suspected of producing an important deep center in GaAs; an EPR signature will be sought. The possibility of other Cr states in InP will be investigated using applied stress enhancement. Progress: Optical absorption of Fe^{2+} in GaAs has been effective in absolute concentration determination, complementing the EPR capability for Fe^{3+}. Uniaxial stress appartus for PL and for EPR have been built. The PL stress system has been able to split the Fe^{2+}PL in InP. Fe^{2+}PL in epilayers of $Al_xGa_{1-x}As$:Fe on GaAs gave a similar splitting due to a lattice mismatch dependent on x, but it was found that the observed centers were resident in the substrates. The EPR stress

apparatus has been used to characterize the Jahn-Teller distortions of the Cr^{2+} and Cr^{3+} centers in GaAs. Cr^{2+} couples only to E-symmetry lattice distortions. Temperature-dependent line broadening was found to agree well with Japanese ultrasonic attenuation studies of Cr^{2+} reorientation rates.

Recent Publications:

"Effects of Uniaxial Stress and Temperature Variation on the Cr^{2+} Center in GaAs", J. J. Krebs and G. H. Stauss, Phys. Rev. B 20, 795 (1979)

"EPR Determination of the Concentration of Chromium Charge States in Semi-insulating GaAs:Cr", G. H. Stauss, J. J. Krebs, S. H. Lee and E. M. Swiggard, J. Appl. Phys., to be published.

"Optically Induced Transient EPR Phenomena in GaAs:Cr", A. M. White, J. J. Krebs and G. H. Stauss, Bull. Am Phys. Soc. 24, 402 (1979) and J. Appl. Phys. to be published.

NR 322-063, California Institute of Technology, "Electronic Properties of Heterojunctions," P. I. - Professor J. O. McCaldin (213) 795-6811, N00014-76-C-1068

The structural and electronic properties of semiconductor-semiconductor and semiconductor-metal interfaces need further study to determine the factors which influence the fabrication of reliable devices and the analysis of possible classes of electron devices. The investigators are studying the factors determining the value of the relative band positions in Schottky barrier junctions and semiconductor-semiconductor heterojunctions. Experimental studies are concentrated on Schottky barriers with the best crystal and electronic matching across the interface. Excellent matching occur for HgX/CdX interfaces, where X is S, Se, or Te. Various expectations from theory and empirical rules have been confirmed in our studies of these systems. One exception, however, has been that the barrier-height enhancement observed to date has been less than predicted. This may be the result of limited thermodynamic stability in CdSe, which can only be n-type. Studies of the analogous telluride interface, where both n- and p-type CdTe are stable, may decide this question. Theoretical studies are being carried out to support the experimental investigations. Progress: The lattice-matched Schottky barrier concept was pursued in considerable detail for the HgSe/CdSe interface. The process producing the best quality of interface was found to be H_2-transport CVD, as judged by microscopy, x-ray structural, backscattering and electrical characterizations. Higher and better-defined barriers were obtained for this interface than is possible with conventional metal/CdSe structures. Studies of the analagous telluride interface, HgTe/CdTe, were begun and best results to date obtained using organotellurium compounds in CVD. Conventional $Au/In_xGa_{1-x}P$ Schottkies were also studied and found to follow the "common anion rule.

Recent Publications:

"The Metal-Semiconductor Interface", J. O. McCaldin and T. C. McGill, Annual Review of Materials Science, 10 (to be published 1980).

"Lattice-matched Heterostructures as Schottky Barriers: HgSe/CdSe", J. Vac. Sci. Tehcnol. 16 (to be published)

"The Schottky-Barrier Height of Au on n-$Ga_{1-x}As$ as a Function of AlAs Contact", Appl. Phys. Lett. 34, 522 (1979).

"The Semiconductor-Conductor Interface", Thin Films, Interdiffusion and Reaction, edited by Poate, Tu and Mayer, New York: Wiley and Sons (1978).

NR 322-066, Lehigh University, "Radiation Damage Processes in Silicon", P. I. - Dr. G. D. Watkins, (215) 861-3961, N00014-76-C-1097

This research effort is devoted to the study of the fundamental properties of simple lattice point defects in the silicon lattice. The broad purpose is to determine the electronic properties of the defects, to understand the mechanisms by which they are formed, and to probe the processes by which they can migrate through the lattice and react with other defects to form complexes. The primary techniques for producing the defects is high energy electron irradiation (1-3 MeV). These are performed in situ at cryogenic temperatures to freeze in the primary defects for study and to separate the production mechanisms from the complex defect reactions when migration and annealing take place. Electron paramagnetic resonance (EPR), optical spectroscopy, and transient- and photo-capacitance spectroscopy are the principal experimental techniques used in this study. The effects of charge state and electronic excitation on the stability, mobility, and reaction kinetics of various defects will be studied. Attempts will be made to understand why the low-temperature electron damage production rates are so different in n- and p- type silicon and to unravel the role of the silicon self interstitial, so far undetected. Theoretical studies will be initiated to help understand the electronic structure of the defects. Progress: Recombination enhanced annealing of interstitial aluminum, interstitial boron, and the lattice vacancy have been identified. In the case of interstitial boron, it has been possible to demonstrate that the motion occurs via a Bourgoin mechanism in which the atom moves from one lattice configuration to another as it alternates in charge between B^{+}_{i} and B^{-}_{i}. Tentative results suggest that both interstitial boron and the lattice vacancy display Anderson "negative U" character. If correct, these represent the first defects in any solid that have been identified to have these important properties.

Recent Publications:

G. D. Watkins, J. R. Troxell and A. P. Chatterjee, "Vacancies and Interstitials in Silicon", Inst. Phys. Conf. Ser. No. 46, 16 (1979).

J. R. Troxell, A. P. Chatterjee, G. D. Watkins, and L. C. Kinerling, "Recombination-enhanced Migration of Interstitial Aluminum in Silicon", Phys. Rev. B19, 5336, (1979)

G. D. Watkins, J. R. Troxell, A. P. Chatterjee, and R. D. Harris, "Ionization Enhanced Migration of Radiation Produced Defects in Silicon", International Conference on Radiation Physics of Semiconductors and Related Materials", Tbilisi, Georgia SSR, Sept. 1979 (to be published).

J. R. Troxell and G. D. Watkins, "Automatic Calibration Circuit for a DLTS Spectrometer", R.S.I. (in press).

NR 322-070, University of California, Santa Barbara, CA, "Mechanism of Electron Transport Across Heterojunctions", P.I. - Prof. Herbert Kroemer, (805) 961-3078, N00014-77-C-0430

The electrical transport across heterojunctions (HJ's), especially isotype HJ's rarely obeys the theoretical predictions of the simple theoretical models that have been proposed for them. To gain a better understanding of this electrical transport is the objective of this contract. Such an understanding is necessary if the full device potential of HJ's is to be realized. Inasmuch as the most important parameter governing electrical transport is the energy band structure of the HJ, most of the initial work was oriented towards a better elucidation of the band structure (especially of GaAs-AlGaAs HJ's) more than towards the transport properties themselves. Progress: We postulated a (technology-dependent) positive interface charge (very likely due to structural defects such as As-vacancies), to explain several discrepancies between theory and observation. The search for a method to determine the interface charge experimentally led to a new C-V profiling technique that determines both interface charge and conduction band discontinuity. The method was successfully demonstrated on LPE-grown structures obtained from Rockwell. The forst successful transport studies have been performed: Some of the Rockwell-grown HJ's were found by the C-V technique to have low interface charges, sufficiently low to suggest rectification, contrary to observations reported by others. Rectification effects of approximately the correct magnitude were found. Our own first MBE-grown GaAs-on-Ge HJ's are about to be evaluated. Other structures will follow.

Recent Publications:

"Photocollection Efficiency and Interface Charges of MBE-Grown Abrupt n(GaAs)-N ($Al_{0.33}Ga_{0.67}As$) Heterojunctions", H. Kroemer, Wu-Yi Chien, H. C. Casey and A. Y. Cho, Appl. Phys. Lett. 33, 749-751 (1978)

"Measurement of Heterojunction Barriers by C-V Profiling", H. Kroemer, Wu-Yi Chien, J. S. Harris, Jr., and D. D. Edwall, submitted to Appl. Phys. Lett.

NR 322-072, University of Wisconsin-Madison, Madison, Wisconsin, "Electron Spectroscopy Studies of Semiconductor Heterojunction Interfaces", P. I. - Prof. M. G. Lagally, (608) 263-2078, N00014-77-C-0474

In order to realize the potential of heterojunction devices, a basic understanding of the local electronic structure and the geometric structure at the semiconductor-semiconductor interface, as well as a correlation between them is required. Using surface analysis techniques such as Auger electron spectorscopy, x-ray photoemission spectroscopy, and low-energy electron diffraction, the site-specific electronic properties of atoms at compound semiconductor surfaces, and adsorbed on such surfaces, will be explored as a function of the geometric structure of the substrate or overlayer. The site-specific density of states at each type of atom will be determined from Auger spectroscopy core-core-valence line shape measurements. This will permit the evaluation of the effects of impurities structural defects in the substrate, or structural defects in the overlayer on the overall electronic nature of the interface. Structural defects in the substrate will be characterized by LEED and will be purposefully induced by, for example, sputtering or poor cleavage. Structural defects in the overlayer will be controlled by controlling growth kinetics. Also of interest is compound formation at the interface. Since the energy discontinuity at a heterojunction interface depends on electronic differences in the materials, and these are in part determined by interfacial defect states, determination of site-specific densities of states from Auger line shapes will elucidate the nature of this

discontinuity. Initially GaAs and Al or Ge adsorption on GaAs will be investigated. Progress: Methods to determine the local densities of states from Auger line shapes have been extended to obtain core level line shapes, which must be known accurately to eliminate their broadening effect on core-core-valence Auger transitions. A stoichiometry effect has been noted in sputtered and reannealed GaAs(110). Because of preferential sputtering and a very narrow stoichiometry range for GaAs, a two-phase mixture of GaAs and Ga results, leading to a changed Ga Auger line shape. This is probably a superposition of Ga and GaAs. Auger line shape measurements of pure Ga are being made. Low-energy electron diffraction is being used to characterize the defect structure on GaAs.

Recent Publications;

1. "Measurement of Valence Band Auger Spectra for GaAs(110) from Ga and As CCV Transitions" G. D. Davis and M. G. Lagally, J. Vac. Sci. Technol. 15, 1311 (1978).

2. "Background Report on Research Opprotunities and Potential Applications of the Quarternary System $Hg_x Mg_y Cd_{1-x-y} Te$," J. D. Wiley and M. G. Lagally, College of Engineering Internal Report #ECE-79-8, University of Wisconsin-Madison.

NR 322-077, Pennsylvania State University, "Study of Sputtering Using Ion-Induced Optical Emission," P. I. - I. S. T. Tsong, 814-865-7341, N00014-78-C-0593

The inelastic outershell processes such as ionization, excitation and neutralization, which occur in sputtering have posed many challenging problems to investigators in recent years. Several controversial models have been proposed to describe the observed phenomena. None of these models, however, is entirely satisfactory. Our primary objective is to make use of one of the inelastic phenomena, viz, ion-induced optical emission, to provide data for investigating excitation, ionization and related energy transfer processes in sputtering. The investigator will undertake experiments to measure: the absolute photon yields for various elements, the distribution of optical emission intensities from different excited states, the velocities of sputtered atoms leaving the target in excited states, the effect of oxygen coverage on metal surfaces on the photon yield and the effect of crystallographic direction on the optical emission. By this approach, we hope to arrive at a unified explanation of the basic mechanisms underlying the inelastic processes in sputtering. Progress: We have measured the absolute photon yields, expressed in photons per sputtered atom, of prominent optical lines from a number of elements. These photon yields for Si and Ni have been compared to the absolute secondary ion yields for the same elements measured by P. Williams of the University of Illinois, and a potential energy curve-crossing model has been developed to explain the observed data. We have measured the optical intensities from different excited states in several elements and found that they do not conform to a Boltzmann distribution. This casts serious doubts on the validity of the 'local thermodynamic equilibrium' or 'plasma' model of ionization and excitation in sputtering. We have measured the velocities of excited atoms by the intensity decay method and found that photons are generally emitted from fast moving sputtered

atoms. This result conforms to our observation on the difference between absolute photon yield and ion yields. Work is currently under progress to determine the effect of oxygen coverage on metal surfaces on the production of photons. Measurements are being carried out on the variation in optical intensity as a function of oxygen pressure and as a function of time after interruption of oxygen flow.

Recent Publications:

1. "Absolute Photon Yields in the Sputter-Induced Optical Emission Process," I. S. T. Tsong and N. A. Yusuf, Appl. Phys. Lett. 33, 999 (1978)

NR 322-080, Fairchild Camera and Instrument Corporation, "Process Variable Dependence and Interrelationship Between Avalanche Injected and Radiation Induced Carrier Trapping in Thermal Oxides," P. I. - B. E. Deal, R. R. Razouk, (415) 493-7250, N00014-79-C-0297.

The determination of the effects of processing variables on the trapping characteristics of electrons and holes in thermal silicon dioxide is an important step towards achieving the optimum process conditions for minimizing hot carrier trapping in VLSI device structures. Also, the selection of those processes which result in the optimum radiation hardened devices, both bipolar and MOS, is still an extremely important consideration in providing integrated circuits for military applications. In this program, the nature and process dependence of carriers trapped in the SiO_2 as a result of substrate avalanche will be compared to those produced by ionizing radiation in oxides prepared under similar conditions. The program is carried out in cooperation with the Naval Research Laboratory in Washington, D.C. Avalanche carrier injection experiments are carried out at Fairchild using a computerized system while the ionizing radiation part of the experiments are carried out at the Naval Research Laboratory. Process: Variables to be investigated include oxidation ambient (Dry O_2, H_2O, and O_2/HCl), oxidation temperature (900°, 1000°, and 1100°C), postoxidation in situ anneal treatments (N_2, Ar), and cooling conditions (O_2 and H_2O fast pull, O_2, Ar, and N_2 slow pull). Progress: New

NR 322-081, University of Washington, "Geometrically Induced Structure in Electron-Excited Appearance Potential Spectra," P. I. - George E. Laramore, (206) 543-3390, N00014-79-C-0371.

When localized atmomic core levels are excited in solids, the high energy (10^2-10^4 eV) final state electrons undergo phase changes as they scatter from the surrounding atoms. This produces oscillatory fine structure in the excitation cross-section as a function of energy which provides information about the local atomic geometry in the region of the excited atom. The extended fine structure above X-ray excited edges (EXAFS) is well known and provides useful information bulk systems. However, it requires access to a synchroton to obtain the necessary high intensity source of continuum X-rays for the excitation process. An alternative procedure is to use a high energy electron beam to excite the core level and to look at the oscillatory fine structure above characteristic loss peaks or above appearance potential thresholds (EFAPS). The latter

measurement can be done in any laboratory and has the advantage of being directly surface sensitive. However, its interpretation is more complex than the corresponding EXAFS experiment in at least three respects: (1) Scattering processes also occur for the initial state electron; (2) There are two final state electrons which means a calculation of the excitation probability involves a convolution of allowable final state processes, and (3) There are no formal selection rules on angular momentum quantum numbers. The research problem is to develop a theoretical formalism to describe the process and to apply it to the analysis of specific experimental data. Progress: A general theoretical formalism has been developed which uses LEED-like wave functions to describe the high energy initial and final state electrons and atomic wave functions to describe the atomic core level wave functions. Initially, a plane wave basis set was used and more recently, a fully renormalized theory developed which uses as basis functions the solutions to the excited atom potential in a muffin-tin approximation. By going to the single scattering limit in the samll atom approximation an EXAFS-like expression was obtained which describes the geometrically induced fine structure in terms of sinusoidal functions. This correlates with other work on the utilization of Fourier transform techniques for data analysis. Current work involves the construction of model potentials and calculation of "bare" excitation matrix elements for use in actual data analysis. Early results on aluminum oxide and nickel oxide surfaces have been quite encouraging and demonstrate both the practical utility of the technique and its surface sensitivity. It appears possible to determine the nearest neighbor spacing for surface atoms to within 0.05% and the technique is applicable to both ordered and disordered systems. Future work will involve comparing more accurate calculations of the scattering phase shifts and excitation matrix elements utilizing self-consistent potentials obtained from X_{α}-cluster calculations with simple potentials constructed from overlapping charge densities and in using more complete model calculations on systems with "known" atomic geometrics to develop more accurate methods for data analysis.

1. "Geometrical Information in Soft X-ray Appearance Potential Spectroscopy," G. E. Laramore, Phys. Rev. B18, 5254-5264, 1978

2. "Effect of the Central Atom Potential on the Extended Fine Structure Above Appearance Potential Thresholds," G. E. Laramore, L. Roelofs, T. L. Einstein and R. L. Park, Phys. Rev. B (in press)

3. "The Use of Fourier Transforms for Analyzing the Extended Fine Structure Above Appearance Potential Thresholds, G. E. Laramore, Surface Sci. 81, 43-55, 1979

4. "Extended Appearance Potential Fine Structure Analysis of Oxidized Metal Surfaces," M. L. den Boer, G. E. Laramore, J. Vac. Sci. Technol. (in press)

5. "Extended Appearance Potential Fine Structure Analysis: Oxygen on Aluminum (100)," J. L. den Boer, T. L. Einstein, W. T. Elam, R. L. Park, L. D. Roelofs and G. E. Laramore, Phys. Rev. Letters (submitted to)

NR 322-082, McMaster University, "Eighth International Conference on Atomic Collisions in Solids, August 12-17, 1979", P. I. - Dr. J. A. Morrison, (416) 525-9140, N00014-79-G-0056

The VIIIth International Conference on Atomic Collisions in Solids was held in Hamilton, Canada during August 13-17, 1979. The proceedings are to be published in a special issue of the Journal of Nuclear Instruments and Methods. All articles for the proceedings have now been forwarded to the publisher. The subjects treated at the conference are linked by a common theme - the interaction of particles with matter. This is an interdisciplinary field encompassing aspects of atomic, nuclear, solid-state and surface physics. The traditional topics of channeling and blocking, ranges, energy loss, sputtering, radiation damage and surface scattering were covered as well as closely related, but slightly more specialized topics, such as projectile and target states, trapping adsorption and emission, surface charge exchange and electron and photon emission. It was the aim of the organizers, not only to present a representative up-to-date picutre of the state of development in these established areas, but also to highlight some of the topics which appear to be of immediate intense interest, such as coherent radiation, molecular ion breakup and high density cascades. Radiation damage in fission and fusion reactors, ion implantation for electronic device fabrication, the manifold practical applications of sputtering, many methods of surface and bulk nuclear analysis are examples of technologies whose underlying physical foundations lie in the atomic collisions in solids area. The policy of this conference series has been, and continues to be, to deal essentially with the fundamental aspects of the subject, including applications only to indicate new areas of interest. Thus techniques and methods first introduced in a basic science context at these conferences have frequently "graduated" to topical conferences relevant to the application. Indeed, the establishment of parallel conference series on specialized topics, such as the Ion Implantation and the Ion Beam Analysis conferences, is a tribute to the vitality and relevance of our subject area.

NR 322-084, National Bureau of Standards, "Analysis of Trace Impurities in Semiconductor Materials", P. I. - S. Mayo, (301) 921-3625, N00014-79-F-0051

High sensitivity trace analytical techniques for semiconductor materials are needed, both for advancing the basic understanding of the materials properties and to aid in the technological growth of microelectronic devices. A new technique involving laser ablation and resonance ionization spectroscopy (LARIS) is being developed for trace chemical analysis of solids. A high power density laser beam is focused on a solid surface to generate a microexplosion. After a time t, the ablated material comes into equilibrium with the surrounding inert atmosphere resulting in a gas specimen appropriate for resonance ionization spectroscopy (RIS) analysis in a proportional counter. In RIS, two different laser probes of frequencies ν_1 and ν_2 are used to induce resonant transitions in the atom under investigation, from the ground state to a first excited state, to a second excited state, and then to the continuum. This process generates photoelectrons with very low energy in the counter, by further acceleration in the counter field they generate a Townsend avalanche which can be detected as a charge pulse by an external circuit. This detection scheme is applicable to many different atoms; it is necessary that there be transitions with frequencies ν_1 and ν_2 which are within the tuning range of available lasers and that sufficient power is available in the laser pulse. Initial research at NBS has been directed toward the detection of sodium. Following demonstration of detection of a single atom of sodium, in a gaseous sample, attention will be

directed toward study of laser ablation mechansims in silicon and gallium arsenide in preparation for initial LARIS experiments. In addition, the effect of the laser ablation plume on the detection system will be investigated. Progress: Single atom detection has been demonstrated for sodium. Sodium introduced as a metal vapor into a proportional counter operated with P-10 gas at about 100 Torr was simultaneously irradiated with two different dye laser beams. The specific transitions selected in sodium atom were 3s (λ_1) → 3p (λ_2) → 4d with λ_1 = 589.0 nm and λ_2 = 568.8 nm; photoionization from the 4d-level is induced by either the λ_1 or the λ_2 lasers. Single atoms detection was established by careful calibration of the proportional counter. Papers describing improvements in the laser probe and the sodium vapor experiment are being prepared for publication.

Recent Publications:

None

NR 322-086, University of Illinois, "Hot Electron Effects of Importance for Micron and Submicron Devices", P. I. - K. Hess, (217) 333-6362, N00014-79-C-0768

As device dimensions are decreased into the micron and submicron range to obtain higher frequencies and/or higher densities, hot carrier effects become important even in devices that are not based directly on hot electron phenomena. We will study, both theoretically and experimentally, some of the more important hot carrier effects that will ultimately limit the performance of CCD, FET, IMPATT, APD, and Gunn effect devices. The specific effects that will be investigated include: The effect of the free carrier thermal conductivity on impact ionization phenomena in IMPATT devices, the influence of carrier density and band structure on the current-voltage or velocity-field characteristic and impact ionization in GaAs, InP, and InGaAsP, the high-field drift velocity in bulk material and at semiconductor-insulator interfaces and the effect of hot electron diffusion on device performance. Progress: New.

MICROWAVE MATERIALS AND DEVICE TECHNOLOGY

NR 251-018, Varian Associates, Inc., "Noncoplanar Power FET", P. I.-S. G. Bandy (415) 493-4000 Ext 3572, S. B. Hyder (415) 493-4000 Ext 3229, C. K. Nishimoto (415) 493-4000 Ext 3557, N00014-75-C-0303

The objective of this contract was to fabricate and evaluate a non-coplanar power FET design using the substrate as the gate and employing low-doped v-grooves under the source and drain areas of the active layer to not only reduce parasitic capacitance but to determine the gate length. Problems with substrate autodoping, bad surface morphology, discontinuous active layer growth, and substrate diffusion into the active layer during anneal of ion-implanted active layers are a few of the problems that have plagued the achievement of obtaining working devices. Optimum techniques were developed towards the solution of any one problem, but typically the techniques would compound the problem in other areas. Progress: Working devices were finally fabricated by etch and growth of vee grooves on a Zn-doped substrate by VPE followed by MBE active layer growth using a newly-developed SnTe doping process and proton bombardment of the field to provide device isolation. Due to the thinness of the active layer, the pinch-off voltage was only 2 V, resulting in low output power. For the 1.5-mm wide device, 134 mW of 1-dB compressed power was obtained at 5 GHz with a gain of 2dB. The contract funds were expended at this point, without renewal, but recommendations for further work would include repeating the run with a thicker active layer. The drain breakdown voltage which was around 10 V could perhaps be improved by separating the p-n junction from the proton-damaged field by an etched groove and using diffusion to separate the p-n junction from the growth interface. Ion-implantation should provide the best solution when either laser or electron-beam annealing of GaAs has been developed to prevent the substrate dopant from diffusing into the active layer and eliminating it.

NR 251-026, Texas Instruments, "Monolithic Push Pull Microwave Amplifier", P. I.-Vladimir Sokolov, N00014-77-C-0657

This work seeks to develop a monolithic class B push pull medium power microwave x-band amplifier module which operates very efficiently, has excellent linearity, high gain and low cost. Progress: Active phase splitters exhibiting gain of 7 db followed by two stage balanced push pull amplifiers exhibiting 15 db gain have been demonstrated at 10 GHz. Circuit techniques to totally eliminate common source inductance and greatly reduce source resistance effects at the fundamental (but not at the harmonic) frequency is underway.

Recent Publications:

1. V. Sokolov and R. Williams, "Monolithic Integration of GaAs Power FETs" Microwave Semiconductor Device, Ckts and Applications Conf. Cornell Univ., August 1979.

2. Technical Report "Monolithic Integration of Microwave GaAs Power FETs", 10/78 to 9/79/

NR 251-027, Varian Associates, Inc., "Submicron FETs Using Molecular Beam Epitaxy", P.I.-S. G. Bandy (415) 493-4000 Ext 3572, C. K. Nishimoto (415) 493-4000 Ext 3557, N00014-77-C-0655

The primary objective of this contract is to fabricate Schottky-barrier FETs having gate lengths of approximately 0.25 micron on GaAs, and evaluate and characterize these devices for high frequency rf performance and evidences for increased velocity overshoot expected for such short gate lengths. This objective necessitated the use of electron-beam lithography to define the gate and the use of an n^+ contact layer to prevent the source resistance from dominating the input impedance. The thin layers required and the abrupt transition needed from the n^+ contact layer to the active layer were easily accomplished with MBE. The nominal structure consisted of an ~0.9 micron thick undoped buffer layer upon which was grown a 0.12 micron thick $3.5 \times 10^{17} cm^{-3}$ doped active layer and a 0.1 micron thick $2.5 \times 10^{18} cm^{-3}$ contact layer. A process was developed to controllably remove the n^+ layer in the gate region using anodic thinning.

Devices were fabricated having gate lengths of about 0.25 micron and the performance appeared to be limited by gate resistance. In addition to the small gate length, the problem of gate resistance appears to be compounded by the resist opening being gradually closed by metal build-up on the edge of the resist defining the gate electrode during the deposition process. The resulting gates are triangular in cross-section and have a maximum height which cannot be exceeded independent of the amount of metal deposited. After unsuccessful efforts to plate up the gates, a new mask set is being used to reduce the gate resistance by a factor of four by halving the device width or by using two gate pads, and this technique is currently under investigation. Efforts also will be made to reduce the source inductance by using plated-through source contacts. Progress: The best results obtained with the original mask set were a noise figure of 1.5 dB with an associated gain of 15 dB measured at 8 GHz. These devices had a gate length of around 0.2 micron and their input resistance appeared to be dominated by gate resistance. Efforts to plate up the gate to decrease the gate resistance resulted in nice mushroom structures, but invariably Au would plate on the edge of the gate and lengthen it considerably. Devices are now being fabricated and evaluated with the new mask set.

NR 251-028, TRW Defense Space Systems Group, "GaAs Integrated Preamp for Navy BPSK Logic Driver", P. I.-Dale Claxton, N00014-77-C-0645

This work seeks to develop a monolithic GaAs preamp and small signal amplifier on a single chip. The device will have a low noise front end followed by two or three cascaded amplifier stages. Electronically controllable gain capability will be included. On chip transmission lines and capacitors will improve performance. Progress: The design for the preamp has been completed. Horizontal gradient impurity doping profiles have been investigated to reduce noise and improve linearity.

Recent Publications:

1. "Monolithic Microwave Preamplifier", A. Benavides, R. Kqelberer, and K. Weller, Technical Report No. 2, September 1979.

NR 251-029, Westinghouse, "Monolithic Broadband Amplifier Techniques", P. I.-Marvin Cohn, N00014-78-C-0268

This work seeks to develop a monolithic amplifier in the 5-10 GHz range using ion implantation technology. Progress: Two stage monolithic amplifiers have been developed exhibiting .5 db gain over the spectrum of interest. Power output consistantly exceeds 0.6 W per millimeter gate periphery.

Recent Publications:

1. Technical Report, "GaAs Monolithic Microwave Subsystem Technology Base" January 1980.

NR 251-030, Varian Associates, Inc., "InGaAs FET", P.I.-S. G. Bandy (415) 493-4000 Ext 3572, S. B. Hyder (415) 493-4000 Ext 3229, C. K. Nishimoto (415) 493-4000 Ext 3557, N00014-78-C-0380

The goal of this contract phase was to grow by VPE active layers of InGaAs having an In percentage of 25% and higher on linearly-graded buffer layers grown on semi-insulating GaAs substrates. Previous work had shown an effective saturated drift velocity greater than that for GaAs with the best evidence being obtained from a device run using 34% In for which a saturated drift velocity of 1.8×10^7 cm/sec was obtained which is 40% higher than the value obtained for GaAs. Poor choice of material parameters, however, resulted in large values of parasitic capacitance and hence poor rf performance. Efforts to reproduce this growth have resulted in highly degraded hazy surfaces for In concentrations above 20%. Only after an H_2 bypass was added to the reactor were good surfaces obtained, and devices are now being fabricated on this material. Efforts in the future will shift towards fabricating devices on InGaAs lattice-matched to InP using a thin InGaAsP layer to increase the gate barrier height. Measurements on InGaAs lattice matched to InP have shown mobilities in the 7000-8000 cm^2/V-sec range at room temperature for 10^{17} cm^{-3} doping. Progress: The use of GaAs substrates from various vendors, lowering the growth and grading rates, and decreasing the mole fraction of $AsCl_3$ only alleviated the problem of poor surface quality incrementally without eliminating it. Devices fabricated on this material all yielded sub-GaAs values of effective saturated drift velocity. Only when an H_2 bypass was installed on the reactor at the end of this contract phase did good surfaces result, and devices are presently being fabricated on this material.

Polishing off the haze on the surface and ion-implanting the active layer resulted in the return of the degraded surface after thermal annealing. Laser annealing studies on GaAs of ion-implanted layers resulted in low mobilities, showing that the laser is incapable of removing all of the lattice damage.

NR 251-031, Naval Ocean Systems Center, "Compatible Dielectric Growth and Characterization for InP Devices", P. I.-D.L. Lile, (714) 225-6591, N0001[illegible] 80WR00089

The demonstration and utilization of the full potential of III-V compounds in high frequency analog and digital applications is hampered by the unavailability of high-quality, interface compatible, dielectrics. The objective of this program of research is the development and characterization of a dielectric system suitable for use with InP. In particular, a dielectric which is com-

patible with InP for microwave integrated circuit applications is being sought using chemical vapor deposition (CVD) techniques. Initial work was centered on the pyrolytic growth of SiO_2 which was evaluated using the usual techniques of C/V, I/V, and Auger profiling. To overcome the limitations of this growth process, a plasma CVD system was constructed which allows for the growth of silica as well as alternate materials at temperatures close to room temperature. Results to date on both the bulk and interfacial characteristics of these materials are extremely encouraging. In particular, the first reported observation of electron inversion on P-type InP was achieved using these CVD layers. During the coming year layers of Si_3N_4 in addition to SiO_2 will be grown and evaluated in both two-terminal MIS and three-terminal FET structures. Progress: During the period 1 Oct 78 through 30 Sep 79 the plasma CVD reactor was constructed and initial checkout was completed. Layers of SiO_2 were grown which were extremely hard and adherent and which had resistivities $\rho \sim 5 \times 10^{15}$ Ω cm. Results on monitor degenerate Si slices indicated that this dielectric is essentially free of dispersion and highly reproducible.

Recent Publications:

1. "Inversion Layers on InP", L.G. Meiners, D.L. Lile and D.A. Collins, J. Vac. Sci. & Technol. (1979) (To be published).

2. "n-Channel Inversion Mode InP MISFET", D.L. Lile, D.A. Collins, L.G. Meiners and L. Messick, Electn. Lett. 14, 657-659 (1978).

3. "Microwave Gain from an n-Channel Enhancement-Mode InP MISFET", L.G. Meiners, D.L. Lile, and D.A. Collins, Electn. Lett. 15, 578 (1979).

NR 251-032, Rockwell International Thousand Oaks, "M.B.E. Grown Heterojunction AlGaAs Confinement Interfaces", P.I.-Daniel Chen, N00014-78-C-0370

This work seeks to exploit M.B.E. grown AlGaAs buffer layers as a means to prevent charge carrier from the GaAs FET active layer from being injected into the substrate. Such a device is expected to exhibit better output conductance than conventional FETs. Also because the effective channel height is thinner the effective end product may be lower than required to sustain a deleterious dipole domain. Progress: AlGaAs layers have been grown which exhibit resistivities of 10^{18} ohm-cm and higher.

Recent Publications:

(Delinquent)

NR 251-033, Raytheon, Waltham, MA., "Lossless Microwave Multiple Milithrow Switch", P.I. - R. Bierig, N00014-78-C-0623

This development seeks to exploit microwave GaAs FETs integrated onto a single semiconductor chip in a monolithic manner so as to provide r.f. microwave signal switching over broad instantaneous bandwidths and without the traditional losses. Progress: 4 pole single throw, 2 pole-2 throw, and single pole-4 throw switches with up to 20 db gain have been demonstrated at x-band.

Recent Publications:

1. Technical Report "Lossless Broadband Microwave Switches", September 1979.

NR 251-034, Raytheon, "Power FET Contact Technology", P.I.- Dr. Robert L. Mozzi, (617) 899-4800 Ext 3765, N00014-78-C-0622

Degradation of alloyed AuGe ohmic contacts on n-type GaAs is a common cause of device failure, particularly at the elevated temperatures and high current densities encountered in power field effect transistors. The objective of this program is to form and evaluate the reliability of alternative contacts which utilize more refractory metal composites such as TiPtAu and which do not rely on themal indiffusion of n-type dopants from the metallization to form the required surface carrier concentration of over $10^{19}/cm^3$.

Such contacts have been made by TiPtAu deposition on n++ layers formed (1) by the adjustment of reactor conditions during the last seconds of epigrowth and (2) by pulse electron beam annealed (PEBA) selenium implants. Our current tasks are to make the grown n++ layers thicker and more reliably reproducible and to make PEBA compatible with FET fabrication. Changes in carrier depth profiles which accompany variations in growth procedures will be measured, in order to learn how to grow thicker n++ layers, and various shielding schemes will be tried to protect FET channels which are otherwise destroyed during PEBA. The thermal and electrical stability of non-alloyed contacts will also be measured. Progress: Ohmic contacts were made by both of the procedures given above. PEBA selenium implants yielded the lowest reported contact resistivity for n-GaAs, $3 \pm 1 \times 10^{-7}$ ohm cm^2. Epigrown n++ layers also formed excellent contacts and were used to make high-performance power FET's (1 watt saturated power at 10 GHz). Shortcomings currently delaying general application of these procedures were discovered and potential remedies were proposed for continuing study.

Recent Publications:

1. "Nonalloyed Ohmic Contacts to n-GaAs by Pulse Electron Beam Annealed Selenium Implants", R.L. Mozzi, W. Fabian, and F.J. Piekarski, Appl. Phys. Lett. 35, 337-339 (1979).

NR 251-035, Rockwell International Thousand Oaks, California "Monolithic Superhet", P.I. - Daniel Chen, N00014-78-C-0624

This work seeks to establish the feasibility of developing a rapidly tunable super-heterodyne microwave receiver on a GaAs chip which exhibits a very low noise figure. RF amplifier, mixer, and first intermediate frequency amplifier will be integrated onto a common chip. Later, the local oscillator will also be so integrated. Noise figure less than 3 db over x-band is believed possible. Progress: A two stage RF amplifier, an i.f. amplifier (500-1000 MHz) and a dual gate FET mixer with source follower have been fabricated and tested. All stages exhibit gain. Mixer output VSWR < 1.3:1.

Recent Publications:

(Delinquent)

NR 251-036, Naval Ocean Systems Center, "Laser Annealing to Improve SOS", P.I.-Ron Reedy, N0001479WR09111

This work seeks to determine how silicon an sapphire material can be substantially improved by laser annealing. Progress: Some mobility improvements have occurred. Aluminum autodoping remains a problem.

Recent Publications:

1. Annual Technical Report, "Laser Annealing of SOS Films", 30 September 79.

NR 251-037, RCA Princeton Labs, "Microwave Phase Rotator", P.I. - Mahesh Kumar, N00014-79-C-0568

This work seeks novel techniques to provide controlled continuous phase control within a microwave amplifier by use of two channels separated by 90 degrees wherein each channel has independent gain control and the outputs of each are summed. Progress: Phase control from 0 to 90° has been demonstrated in the 4-8 GHz spectrum. Discrete devices were used.

Recent Publications:

None-New

NR 251-039, Texas Instruments Inc., "Silicon-on-Insulator Microwave FETs", P.I. - Hon-Wai Lam, (214) 238-4348, N00014-79-C-0790

Silicon-on-insulator (SOI) is an attractive material for fabrication of microwave and very high speed circuits. The only available SOI material to date is silicon-on-sapphire (SOS), which has the problems of poor silicon epi quality, high dielectric constant of sapphire, auto doping of the silicon epi by the substrate and its high cost. It has been demonstrated that laser annealing of LPCVD polysilicon on insulator resulted in enhanced gain growth[1] and devices with performance comparable to those fabricated on SOS can be fabricated on laser annealed LPCVD poly on oxide and nitride[2].

This research focuses on the issues of the correlation of device performance with defect density, the carrier mobility profile throughout the thickness of the silicon film and the effects of the substrate material on device performance. The goal of this research is to investigate if laser annealed SOI suffers the same intrinsic difficulties of SOS, and if SOI is a suitable material for microwave IC application.

A scanning CW laser system is used for the laser annealing of LPCVD polysilicon on oxide and nitride substrates. Defects in the laser annealed material are revealed using a defect etch and are studied using a SEM. n-MOSFETs will be fabricated to study device performance and to profile carrier mobility.

Recent Publications:

1. J. F. Gibbons, K. F. Lee, T. J. Magee, J. Peng and R. Ormond, Appl. Phys. Lett., 34, 831 (1979).

2. A. F. Tasch, Jr., T.C. Holloway, K.F. Lee and J.F. Gibbons, Elect. Lett., 15, 435 (1979).

GIGABIT LOGIC

NR 383-039, Hughes Research Laboratories, "Monolithically Integrated FETs and TEDs for Gigabit Shift Register", P.I. - G. O. Ladd, N00014-77-C-0380

This work seeks to combine an FET and a TELD into one hybrid device via ion implantation. The hybrid device offers speed and power advantages over exclusively FET or exclusively TELD technology. A gigabit shift register will be built with the hybrid devices. Progress: TELDs and FETs have been successfully fabricated on the same monolithic chip. FETs are ion implanted. TELDs have capacitative gate output signal pick-offs.

Recent Publications:

(Delinquent)

NR 383-040, NBS, Boulder, "JJ A/D Converter", P.I. - Don McDonald, N00014-77-F-0048

This work seeks to evaluate a superconducting quantum interference device (SQUID) as the quantizer of a Josephson junction analog to digital converter. Effective clock speeds of up to 30 GHz are envisioned. Progress: Gold alloy Josephson lead junction devices have been fabricated and successfully tested through multiple cycles from $4^{o}K$ to room temperature. A 6-bit A/D converter has been fabricated and tested up to clock speeds of 1 GHz. At 1.2 GHz, significant cross-talk renders the output unreliable.

Recent Publications:

1. Annual Report, "Josephson A/D Converter Development", for period May 1, 1977 - October 31, 1979.

NR 383-046, RCA, "High-Energy Ion Implantation for Multigigabit-Rate GaAs Integrated Circuits", P.I. - S.G. Liu (609) 734-2952, S.Y. Narayan (609) 734-2036, N00014-78-C-0367

Multigigabit-rate GaAs ICs require selective definition of n-layers with doping ranging from 10^{16} to $10^{19}cm^{-3}$ and thicknesses ranging from 0.15 μm to 1.0 μm for the realization of active elements such as TELDs, FETs, Schottky barrier diodes, etc. To achieve this objective, we will investigate 1) the implantation of silicon over an energy ranging from 50-1200 keV into qualified SI GaAs substrates and high-resistivity epitaxial buffer layers, 2) thermal and laser annealing of GaAs wafers following single or multiple implantation, 3) the depth distribution of mobility and carrier concentration in the implanted and annealed layers, 4) the formation of non-alloyed ohmic contacts onto heavily implanted laser annealed GaAs, 5) the trap levels by using the DLTS measurement, and 6) the impurity profile by SIMS measurement. Progress: During the period October 1, 1979 to September 30, 1979, high-energy implantation of Si into semi-insulating GaAs at energy levels from 40 to 1200 keV were successfully demonstrated. A projected range of up to 1.1 μm was measured by secondary ion mass spectroscopy (SIMS). Electrical activation following thermal anneal equal to or better than that of low energy implantation was obtained. The annealing of high-dose implants using pulsed Nd:Glass and ruby lasers was successfully formed on heavily-implanted laser-annealed GaAs. The profiles and range statistics of ^{28}Si implanted GaAs were studied, and based on the information obtained on SI GaAs substrates by multiple implantation and thermal annealing.

Recent Publications:

1. S. G. Liu, C. P. Wu, and C. W. Magee, "Annealing of Ion-Implanted GaAs with Nd:Glass Laser," AIP Conference Proceedings, No. 50, p. 603, New York, 1979.

NR 383-047, TRW, Redondo Beach, California, "TELD A/D Converter", P.I. - Dale Claxton, N00014-78-C-0634

This work continues the effort previously developed under Contract N00014-76-C-0743 where individual bit cells of a monolithic pipelined, successive approximation A/D converter using both TELDs and FETs on a common chip which was demonstrated to operate at sample clock frequencies up to 8 GHz. This new work will combine up to 5 of the cell samples into an A/D converter. Progress: Stability problems originally encountered have been overcome, but the program is behind schedule.

Recent Publications:

(Delinquent)

NR 383-049, The Aerospace Corporation, El Segundo, California, "Microwave SQUID Analog to Digital Converters", A. H. Silver, (213) 648-5840, N0001479MP90010

Josephson junction technology is applied to achieve analog to digital conversion at high sensitivity, high sampling rates, and large dynamic range. A conceptually simple approach using a SQUID quantizer followed by a binary counter chain of SQUIDs has been adopted for development. Basic issues of SQUID performance as a high speed scaler, coupling of SQUIDs, signal rates, and margins were analyzed. Next year the problems of sampling, buffer memory, readout, and front-end sensitivity and burnout will be addressed. The fabrication technique will be further extended to include Nb ground planes on Si substrates. Progress: The Pb-In alloy junction process has been developed using a two film overlay geometry. Computer simulations of operation of a quantizer and two scalers have been performed, demonstrating analog to binary conversion with adequate margins to picosecond pulse widths. The influence of inter- and intra-SQUID delays, junction capacitance, and damping have been observed. This leads to general design criteria for SQUIDs connected by superconducting microstriplines. Preliminary experiments to demonstrate microwave frequency division with coupled SQUIDs were performed.

Recent Publications:

1. "Fast Analog to Digital Conversion with SQUIDs", J. P. Hurrell and D. C. Pridmore-Brown, First Specialty Conference on Gigabit Logic for Microwave Systems, p. 4-8 (1979).

NR 383-051, Texas Instruments Incorporated, "Cryogenic Switching", P.I. - M. R. Namordi, (214) 238-3626, F. H. Doerbeck, (214) 238-5140, and W. R. Frensley, (214) 238-3045, N00014-79-C-0789

The propagation delay and speed of operation of electronic logic circuits are fundamentally related to the transport properties of the charge carriers. Two

of the more important material parameters which are particularly significant to achieving maximum circuit speeds are mobility and saturation velocity. Since both of these parameters are improved at 77K vis-a-vis 300K, faster switching speeds are anticipated at cryogenic temperatures. The overall objectives of this research are, therefore, to determine the switching speed advantage to be gained at 77K and to develop the processing technology necessary to bring it to fruition.

Because the fastest logic circuits have been fabricated in GaAs, the material of choice for this research is GaAs. The first question needing resolution is to determine which material parameter, mobility or saturation velocity, is dominant in determining circuit speed. Accordingly, high quality vapor phase epitaxial material, doped over the low-10^{15} to high-10^{16} cm^{-3} range, is being grown with particular attention towards minimizing compensation and achieving high crystalline perfection. Van der Pauw and fat-FET mobility measurements are planned at 300 and 77K to establish the mobility ratio, R_μ, as a function of doping concentration. Similarly, the static electrical characteristics of normal FETs (gate lengths of 1-2 μm) help establish the saturation velocity ratio, R_{VS}. The propagation delay of single stage inverters (and, with further process development, ring oscillators and exclusive OR circuits) fabricated on such material is planned to determine the speed advantage ratio, R_τ. These results will help us to deduce which material parameter is dominant in determining maximum speed of operation while simultaneously aid in establishing the GaAs material and device specifications for optimum low temperature operation. Progress: New

NR 383-052, Ionomet Company, Inc., "Ultrasensitive Electron (Soft X-Ray) Silver Halide/Chalcogenide Negative or Positive Inorganic Resist", P.I. - J. M. Lavine (617) 787-0454, N00014-79-C-0788

Although this contract is new, during the first month we have established procedures for evaporating As_2S_3 and have purchased and installed an evaporation system for AgBr. We have evaporated ultrasensitive films of AgBr. Composite structures of As_2S_3/AgBr have been prepared and successfully tested with optical radiation. Progress: New

Recent Publications:

1. "A Novel High-Speed Electron Resist," to be presented, Paper No. 3.7, International Electron Devices Meeting, Washington, DC, Dec. 3, 1979.

ANTENNAS AND PROPAGATION

NR 371-008, University of Kentucky Research Foundation, Lexington, Kentucky, "Extraction of the SEM Description of Transient Scattering from Measured Data", P. I. - L. Wilson Pearson, (606) 257-1644, N00014-77-C-0362

The project is oriented toward obtaining the complex natural resonance characterization of the electromagnetic scattering from finite-extent structures. The method involves the probing of transient surface currents excited on the structure by a known field, followed by computational space/time deconvolution of the excitation field. The deconvolution is conducted in terms of ploe/residue decomposition of the measured time history. The aggregate data from many current probing sites on the object are sorted to form a pole/mode sum representation intrinsic to the object. This representation can be used construct responses for new excitation waveforms and field orientations. The past year's effort has centered on applying the extraction methodology to the canonical structure of a thin cylinder and on developing a noise-tolerant pole/residue processor. The cylinder study served to demonstrate the feasibility of the extraction process and to extend the use of miniature loop probes of the form pioneered by R. W. P. King and his colleagues to applications in transient measurements. The signal processing effort has led to a new iterative pre-filtering scheme which has the potential for recovering poles and residues from data containing a significant level of noise corruption. The next year's work is directed toward the development of techniques for implementing the extraction on an object suspended in open air. (The previous work has used ground-plane symmetry, thus eliminating the possibility of recovering one of the tow symmetry classes of modes.) The"free-field" configuration presents two major obstacles. The first is the conveying of the measured data away from the object through a medium which does not appreciably interact with the object under test. The second is the adequate characterization of the incident field illuminating the object. A novel approach is being used to address the first of these difficulties. An "Optically Coupled Sampling Scope" (OCSS) is being developed which links the sampling bridge of a broadband sampling oscilloscope to the scope mainframe by way of fiber optics. This system should be useful in other free-field measurement applications.

Recent Publications:

L. W. Pearson and D. R. Roberson, "The Extraction of the Singularity Expansion Description of a Scatterer from Sampled Transient Surface Current Response", to be published in IEEE Trans. Ant. and Prop.

L. W. Pearson, D. R. Wilton, R. Mittra and R. Hsu, "Conditions of Validity for Class 1 and Class 2 SEM Coupling Coefficients", 1978 USNC/URSI Fall Meeting, Boulder, Colorado, November 1978.

T. L. Henderson, "Noise Processes Resulting from Use of Sampling Oscilloscopes in SEM Measurements", 1978 USNC/URSI Fall Meeting, Boulder, Colorado, November, 1978.

L. W. Pearson and Y. M. Lee, "The Use of King-type Current Probes for Broadband Transient Measurements", USNC/URSI National Radio Science Meeting, University of Washington, Seattle, Washington, June 1979.

D. R. Wilton and L. W. Pearson, "Analytic Properties od Some SEM-Derived Quantities", USNC/URSI National Radio Science Meeting, Boulder, Colorado, November, 1979.

L. W. Pearson and J. R. Auton, "A Critique of the Pencil-of Functions Pole Extraction Method in the SEM Context", USNC/URSI National Radio Science Meeting, Boulder, Colorado, November, 1979.

J. R. Auton and L. W. Pearson, "An Adaptive Filering Algorithm for the Identification of SEM Poles", USNC/URSI National Radio Science Meeting, Boulder, Colorado, November, 1979.

NR 371-010, University of Colorado, Boulder, Colorado, "The Development of Digitally Controlled, Wide Bandwidth Adaptive Array Processors Using Highspeed, Low-Order Quantizers", P. I. - Professor Lloyd J. Griffiths, (303) 492-7327, N00014-77-C-0592

This work is concerned with the application of digital adaptive beamforming methods to wide bandwidth antenna arrays which operate in the microwave frequency range. The current state of digital circuitry technology does not allow direct digitization and processing of the array element outputs. Further, because of the wide bandwidths involved, simple gain/phase steering at the elements does not provide sufficient protection against interfering sources. The array processing configuration developed at Colorado involves a hybrid beamforming structure which uses analog circuitry to form the beam output. The system employs a sidelobe cancelling path in which array signals are passed through tapped-delay lines containing taps which are constrained to have values of +1, 0, or $^{-}$1, as determined by a digital controller. Thus, simple switches are used at each tap point. The digital controller receives digitized inputs using high speed sample and hold circuits with aperture times the order of 100 picoseconds. A modified gradient descent algorithm is employed to set the delay line switches to their appropriate values. Progress: Recent work at Colorado has focused on the development and analysis of adaptive algorithms for use with this hybrid structure. A particularly simple algorithm, termed the accumulated gradient LMS method has been shown to provide adaptive null depts on the order of 20 to 30 dB. Both simulated and field-recorded data have been employed in this study. In addition, a mathematical model has been developed which can be used to study the convergence properties of the algorithm. Future work will focus on the ability of the hybrid processor to track non-stationary interference such as that having a time varying angle of arrival.

Recent Publications:

"The Use of High-Speed, Low Order Quantizers in Wideband Adaptive Arrays", L. J. Griffiths and C. W. Jim, IEEE/AP-S Symposium Proceedings, Washington, DC, May 1978.

"Hybrid Adaptive Array Processing Using High-Speed A/D Converters", L. J. Griffiths, and C. W. Jim, 1979 IEEE/MTT-S International Symposium on Gigabit Logic for Microwave Systems, Orlando, Florida, May, 1979.

"A New Digital Adaptive Beamforming System for Microwave Arrays", L. J. Griffiths, and C. W. Jim, Proceedings Septieme Colloque Sur Le Traitement Du Signal et Ses Applications, Nice, France, June, 1979.

"A New Approach to Linearly-Constrained Adaptive Beamforming", L. J. Griffiths, submitted to Geophysics, July, 1979.

"Signal Processing Methods for Large Bandwidth Adaptive Arrays", C. W. Jim and L. J. Griffiths, National Radio Science Meeting (URSI), Boulder, Colorado, November, 1979.

NR 371-012, The University of Texas at Austin, Austin, Texas, "Studies of Non-Reciprocal Effects in Planar Submillimeter to Optical Waveguiding Structures", P. I. - Tatsuo Itoh, (512) 471-1072, N00014-79-C-0553

Understanding of field displacement type non-reciprocal wave phenomena is important for future development of non-reciprocal devices such as isolators and circulators for millimeter and submillimeter wave applications. This project is concerned with investigation of these phenomena in various planar and quasi-planar dielectric waveguide structures containing gyrotropic or anisotropic materials. For several promising structures, qualitative as well as quantitative studies are needed for the propagation constants and the field distributions in these waveguides. Then, we can proceed to the investigation of implementing selective (in terms of the propagation direction) scattering, leakage or absorption mechanisms as an integral part of the waveguiding structure. Various mechanisms will be compared and effectiveness of these composite structures studied as non-reciprocal devices. Some experimental tests will also be conducted whenever needed. Progress: We started the project by first identifying typical canonical problems which are analytically tractable and yet provide some physical insight to more practical structures. Based on this study, we selected non-symmetric three layer slab structures in which one or two layers are characterized by tensor permeability or permittivity. We formulated the problem and numerically analyzed propagation characteristics of modal fields as a function of frequency and applied DC magnetic bias. We obtained propagation constants and field distributions of traveling dominant slab modes. In a more practical structure, the width of the anisotropic slab is no longer infinite. To analyze such a structue, we contemplated application of the effective dielectric constant approach. We compared two subclasses of this approach in the case where anisotropy is removed. The results of these two compare favorably.

NR 371-014, Rochester Institute of Technology, "The Applications of the Pencil-of-Function Method to Radar Target Identification", P. I. - Tapan K. Sarkar, (716) 475-2165, N00014-79-C-0598

The objective is to investigate the use of the pencil of functions method for determining the natural resonances of conducting bodies in order to determine the potential for real time target identification, discrimination, or passive IFF by Naval radars. The initial research involves theoretical development and computer modeling including statistical studies of the pencil of functions method, investigation of the use of first order filters to replace integrators, and of the effect of finite record length on the accuracy with natural resonances can be determined, and development of a test to distinguish the desired signal (describable by complex exponentials) from noise. Progress: New.

Recent Publications:

"Radar Cross Sections of Conducting Bodies Over a Lossy Half Space", T. K. Sarkar and R. F. Harrington, Radio Science, to be published.

NR 371-021, Ohio State University, Columbus, Ohio, "Electromagnetic Research". P. I. - Professor Carlton H. Walter, (614) 422-6194, N00014-78-C-0049

This program is a tightly coordinated research effort by ten scientists in three major thrust areas. The largest thrust is in developing methods to treat the scatter and coupling of electromagnetic waves, particularly involving bodies of complex shapes such as ships, aircraft and missiles. The geometric theory of diffraction (GTD) is being extended by finding diffraction coefficients for complex but common geometries such as edges of convex or concave sheets using asymptotic or moment method (MM) techniques. Hybrid methods combining (GTD) and (MM) are being developed that will be valid at both high and low frequencies as well as near resonance. Antenna synthesis by means of characteristic modes is being investigated. The second largest thrust is in research on target identification, and transient effects. The use of complex natural resonances, as well as matched-filter response, is being investigated as a target identification algorithm, with very promising preliminary results. The transient research is concentrating on the "K-pulse", namely the waveform which, when passed through a filter, produces a delta function. This could lead to the ability to radiate extremely broadband pulses, or to a passive IFF (friend or foe) system by matching a radar pulse to the desired target response, or to minimization of antenna ringing and hence reduced intersymbol interference in high data rate communication. The specific relationship between natural resonances and body geometry is being investigated. The phenomenon of microwave generation through irradiation of metallic objects with laser pulses is being investigated. Finally, the problem of finding optimal modulation waveforms for use in communications systems that incorporate adaptive antennas using the LMS algorithm for jamming supression is being addressed. Progress: A method was developed to treat scattering from a convex surface where the incident wavefront can be arbitrary. A compact asymptotic solution was developed for the fields radiated by antennas on convex surfaces. A novel torus horn antenna was invented using hybrid method of moments - geometric theory of diffraction method. The antenna is very broad band, and features extremely low peak sidelobes. It would be suitable for use in spread spectrum systems where short range low probability of intercept through sidelobe control is essential. An analytical method to determine the number of taps required as a function of bandwidth for adaptive antenna arrays was developed.

Recent Publications:

E. H. Newman and D. M. Pozar, "Electromagnetic Modeling of Composite Wire and Surface Geometries", IEEE Transactions on Antennas and Propagation, AP-26, 784, 1978.

W. D. Rodgers and R. T. Compton, Jr., "Adaptive Array Bandwidth with Tapped Delay-Line Processing", IEEE Trans., AES-15, 21, 1979.

NR 371-022, Lawrence Livermore Laboratory, "Radiation Field Analysis and Synthesis Using Prony's Method", P. I. - Edmund K. Miller, (415) 422-8312, N00014-79-E-0024

The work in question addresses the issue of array synthesis and source imaging. Advanced digital signal processing methods and system identification techniques are being applied to the problem including Prony's method, which is a technique for

obtaining the parameters of a series of complex exponentials. The current research work addresses issues in array realizability, pattern specification, and alternate approaches. In realizability, research will be focused on achieving a realizable solution for the array by investigating necessary and sufficient conditions. The synthesis of an array from a specified pattern can proceed from a complete specification of a far zone field (magnitude and Phase) or an incomplete specification (magnitude and assumed phase) or a power pattern. Another important aspect is the angular range over which the pattern is specified. The effects of each of these on the realizability of an array are being investigated. In addition, other system identification and signal processing methods for use in synthesis and imaging are being explored. Progress: Progress to date has shown that Prony's method is applicable to linear array synthesis. The technique has been applied to patterns specified by functional behaviors such as $\sin^N$. The dependence of the synthesis on the number of poles used in the Prony process has been investigated, and a systematic increase in aperture size and the reduction in sidelobe levels was observed as the number of poles was increased. Noise effects on patern realizability have also been investigated. The issue of realizability was looked into (i.e., the systhesis giving poles that are purely real to correspond to physically realizable locations) and research was performed in the imposition of realizability constraints. Necessary (but not sufficient) conditions have been derived for this.

Recent Publications:

"Synthesis of Prescribed Patterns Using Prony's Method", E. K. Miller, D. L. Lager, and J. T. Okada, in preparation as a Lawrence Livermore Laboratory Report. (1979)

"Imaging of Linear Source Distributions", E. K. Miller and D. L. Lager, Presented at the National Radio Science Meeting held at the University of Colorado at Boulder, Colorado (November 6-9, 1978)

"Imaging the Apparent Sources of Straight Wires and Scatters Using Prony's Method", E. K. Miller and J. T. Okada, in preparation as a Lawrence Livermore Laboratory Report. (1979)

"Linear Array Synthesis Using Prony's Mehod", E. K. Miller and G. J. Burke, Presented at the National Radio Science Meeting and Bioelectromagnetics Symposium held at the University of Washington, Seattle, Washington (June 18-22, 1979).

"Inversion of One-Dimensional Scattering Data Using Prony's Method", E. K. Miller and D. L. Lager, Lawrence Livermore Laboratory Report No. UCRL-52667 (February 12, 1979).

NR 371 088, University of Colorado, "Electromagnetic Susceptibility Study of Metallic Enclosures and Electronic Circuits", P. I. - David C. Chang, (303) 492-7539, N00014-76-C-0318

The objective of this project is to understand the interference and susceptibility phenomena caused by penetration of electromagnetic energy into cylindrical enclosures, and to the electronic circuits placed inside the enclosures. Currently, efforts are expended in obtaining analytical description of the induced currents and charges on these enclosures, modelled by a single or concentric thin cylinder, over a broad frequency range as well as their transient characteristics. While the project's emphasis is analytical, it is also supplemented by experimental investigation on composite panels. Progress: Perhaps the most important achievement during

the last funding period is the completion of a unified theory for thin-wire enclosures which act like antennas, over a very broad frequency range where their lengths vary from electrically very short to very much longer, compared with a freespace wavelength; and their radii from very thin to moderately thick where the circumference is comparable to a free space wavelength. Simple formulas are derived which allow us to study statistically the performance of these cylinders in an unspecified plane-wave envirnoment, without excessive computation. To allow for penetration schemes typically encountered in a realistic system, we have also extended the theoretical analysis to include end penetration, loaded cylinders, concentric cylinders, as well as transient phenomena.

Recent Publications:

"Theory on Small, Radiating Apertures in the Outer Sheath of a Coaxial Cable", David C. Chang, IEEE Trans. Antennas and Propagation, Vol. 26, No. 5, 674-682, 1978.

"Simple Formula for Current on a Cylindrical Receiving Antenna", David C. Chang, S. W. Lee and Lawrence W. Rispin, IEEE Trans. Antennas and Propagation, Vol. 26, No. 5, 683-690, 1978.

"The Use of Effective Aperture Relations for the Calculation of the Input Conductance of Electrically Small Antenna", Lawrence W. Rispin and David C. Chang, Scientific Report No. 40, Electromagnetics Laboratory, University of Colorado, Boulder, Colorado. Accepted for publication in IEEE Trans. Antennas and Propagation in 1980.

"Analytic Determination of SEM Poles and Related Coefficients for Thinwire Dipole Antennas", David C. Chang, S. W. Lee and Ahmad Hoorfar, Proceedings 1978 National Radio Science Meeting, Nov. 1978.

"On Electrically Thick Cylindrical Antennas of Finite Length", Lawrence W. Rispin and David C. Chang, Proceedings 1979 Spring URSI Meeting, Seattle, Washington, June 1979.

"Junction Effect of Two Thin, Coaxial Cylinders of Dissimilar Radius", David C. Chang, Proceedings 1979 Spring URSI Meeting, Seattle, Washington, June 1979.

"A Unified Theory for Thin Wire Antennas of Arbitrary Length", Lawrence W. Rispin and David C. Chang, Proceedings 1979 International Symposium on Antennas and Progagation, Seattle, Washington, June 1979. Also, Scientific Report. 38, Electromagnetics Laboratory, University of Colorado, Boulder, Colorado, January 1980.

"A Generalization to King's Short Antenna Theory", Lawrence W. Rispin and David C. Chang, submitted to IEEE Trans. Antennas and Propagation.

NR 371-147, Polytechnic Institute of New York, "Nonlinear and Turbulent Wave Interactions", P. I. - N. Marcuvitz, (516) 694-5500, N00014-76-C-0176

Progress: Our general area of concern is with the determination of an optimum balance between analytical and computational techniques for wave propagation problems in nonlinear and turbulent media, as well as inhomogeneous and nonstationary linear media, with emphasis on ionospheric applications. In the past period we investigated the use of novel quasiparticle method for calculation of wavepacket propagation

in various media; [1]this method does not suffer from troublesome caustic difficulties found in conventional ray treatments and promises computational simplifications. Our previously reported studies on renormalization techniques in nonlinear turbulent wave propagation were generalized to include 2n-point correlation properties. [2]We have continued to exploit a novel technique[3]for treating plasma instabilities of interest for ionospheric irregularity phenomena. Our ionospheric studies of type II irregularities in the equatorial electrojet have corrected some early misconceptions about the application of direct interaction methods to this system and clarifies what the standard theory can and cannot predict.

Recent Publications:

"Quasiparticle View of Wave Propagation", N. Marcuvitz, POLY-MRI-Report No. 1402-79, to be submitted to Proc. I.E.E. (invited paper).

"Quasiparticle Method in Nonlinear Wave Propagation", N. Marcuvitz, invited paper at National Radio Symposium, Seattle, Washington, June 1979, to be published in Nonlinear Electromagnetics, Pergamon Press.

"Renormalization of Maxwell's Equations for Turbulent Plasma", S. Barone, accepted for publication in Phys. Rev. (A) (1979).

"A New Approach to Some Nonlinear Fluid Dynamic Problems", S. Barone, Phys. Letters, 70A, 260 (1979).

"Nonlinear Theory of Type II Irregularities in the Equatorial Electrojet", S. Barone, accepted for publication in Phys. of Fluids (1979).

SPACE RADIATION EFFECTS

NR 323-001, University of Iowa, "Solar Radiations in Near Space and Their Effects on the Earth's Magnetosphere and Ionosphere", P.I.-Professor James A. Van Allen, (319) 353-4531, N00014-76-C-0016

This contract provides basic support for a broad based program of investigations by space techniques on:
(a) All aspects of the energetic particles that are trapped in the earth's magnetic field and are transiently present in the outer magnetosphere including the magnetospheric tail of the earth; and of the solar, interplanetary, and terrestrial phenomena that are associated with these radiations--solar flares, interplanetary magnetic fields and plasmas, aurorae, geomagnetic storms, corpuscular heating of the atmosphere, electromagnetic waves and magnetostatic and electrostatic fields (both constant and variable) in the magnetosphere, plasma flows in the magnetosphere, and the ionospheric effects of particle precipitation.
(b) Exploratory studies of the magnetospheres of Jupiter and Saturn.
(c) Interplanetary propagation of galactic cosmic rays and solar energetic particles. Progress: During the coming year, knowledge of the earth's magnetosphere will be applied to the analysis and interpretation of recently acquired data on the magnetospheres of Jupiter and Saturn in the spirit of developing a comparative, comprehensive theory of planetary magnetospheres. Data on the earth's magnetosphere and on interplanetary phenomena are ~~being~~ received currently from three earth satellites and four interplanetary spacecraft. Emphasis is on the study of plasma physical phenomena in the natural environment of earch.

Recent Publications:

1. "Three-Dimensional Plasma Measurements Within the Earth's Magnetosphere", L.A. Frank, K.L. Ackerson, R.J. DeCoster, and B.G. Burek, Space Science Reviews, 22, 739-763, 1978.

2. "Magnetospheric Plasma Waves", S.D. Shawhan, Solar System Plasma Physics (A 20th Anniversary Review), edited by C.F. Kennel, L.J. Lanzerotti, and E.N. Parker, Chapter III-F, pp. 211-270, 1978.

3. "Further Observational Support for the Lossy Radial Diffusion Model of the Inner Jovian Magnetosphere", C.K. Goertz, J.A. Van Allen, and M.R. Thomsen, J. Geophysics, Res., 84, 87-92, 1979.

4. "Field-Aligned Currents, Convection Electric Fields and ULF-ELF Waves in the Cusp", N.A. Saflekos, T.A. Potemra, P.M. Kintner, Jr., and L. Lauer Green, J. Geophys. Res., 84, 1391-1401, 1979.

5. "Energetic Electrons in Jupiter's Dawn Magnetodisc", J.A. Van Allen, Geophys. Res. Letters, 6, 309-312, 1979.

6. "Jovian Magnetosphere-Satellite Interactions Aspects of Energetic Charged Particle Loss", M.F. Thomsen, Rev. Geophys. and Space Physics, 17, 369-387, 1979.

7. "Plasma in the Jovian Current Sheet", C.K. Goertz, A.W. Schardt, J.A. Van Allen, and J.L. Parish, Geophys. Res. Letters, 6, 495-498, 1979.

8. "High-Resolution Spectrograms of Ion Acoustic Waves in the Solar Wind", W.S. Kurth, D.A. Gurnett, and F.L. Scarf, J. Geophys. Res., 83, 3413-3419, 1979.

9. "Propagation of a Forbush Decrease in Cosmic Ray Intensity to 15.9 AU", J.A. Van Allen, Geophys. Res. Letters, 6, 566-568, 1979.

10. "Intense Electrostatic Waves Near the Upper Hybrid Resonance Frequency", W.S. Kurth, J.D. Craven, L.A. Frank, and D.A. Gurnett, J. Geophys. Res., 84, 4145-4164, 1979.

11. A Correlation Between Auroral Kilometric Radiation and Inverted-V Electron Precipitation", J.L. Green, D.A. Gurnett, and R.A. Hoffman, J. Geophys. Res., 84, 5216-5222, 1979.

NR 323-004, University of California, Berkeley, "Vector Electric Field Measurements on Balloons and Satellites", P.I.-Dr. F. S. Mozer, (415) 642-0549, N00014-75-C-0294

In situ measurements of AC and DC electric and magnetic fields, plasma density irregularities, and plasma density and temperature are taken by the ONR 104 experiment on the high altitude polar orbiting satellite S3-3. These data are analyzed to determine the cause of auroral particle acceleration, field aligned currents, ExB motions, and the cause of ionospheric irregularities. Progress: The poleward field aligned current sheet was found to coincide with the polar cap boundary. The energy source for the intense DC electric fields that cause electron precipitation may be extremely low frequency Alfven waves which are dissipated by the electrostatic ion cyclotron instability. A possible auroral substorm precursor was discovered. It consists of a narrow pillar of ionization associated with keV electron precipitation.

Recent Publications:

1. R.R. Vondrak, R.D. Sharp, F.S. Mozer, C.A. Cattell, R.B. Torbert, J.F. Fennell, and P.F. Mizera, "An Ionospheric Precursor of an Auroral Substorm as Observed by the Chatanika Radar and the S3-3 Satellite", EOS, 59, 1167, 1978.

2. C. Cattell, R. Lysak, R.B. Trobert and F.S. Mozer, "Observations of Differences Between Regions of Current Flowing Into and Out of the Ionosphere", Geophys. Res. Lett., 6, 621, 1979.

3. H.C. Koons, M.H. Dazey, and B.C. Edgar, "Satellite Observation of Discrete VLF Line Radiation Within Transmitter-Induced Amplification Bands", J. Geophys. Res., 83, 3887, 1978.

4. R.H. Holzworth and F.S. Mozer, "Direct Evaluation of the Radial Diffusion Coefficient Near L=6 Due to Electric Field Fluctuations", J. Geophys. Res., 84, 2559, 1979.

5. C. Cattell, M. Temerin, R.B. Torbert, and F.S. Mozer, "Observations of Downward Field-Aligned Currents Associated with Upward Ions", EOS, 59, 1155, 1978.

6. M. Temerin, P. Kintner, and F.S. Mozer, "The Coherence of Electrostatic Ion Cyclotron Waves", EOS, 59 , 1155, 1978.

7. R.L. Lysak, M.K. Hudson, M. Temerin, "Enhanced Heating by Coherent Electrostatic Ion Cyclotron Waves", EOS, 59, 1155, 1978.

8. J.R. Wygant, R.H. Holzworth, and F.S. Mozer, "Simultaneous Magnetically Conjugate DC Electric Field Measurement", EOS, 59, 1157, 1978.

9. R.B. Torbert, and F.S. Mozer, "A Large Scale Region of Parallel Electric Field Poleward of the Magnetopause", EOS, 59, 1158, 1978.

10. M.K. Hudson, R.L. Lysak, and C. Cattell, "Perpendicular Currents in the Auroral Magnetosphere", EOS, 59, 1170, 1978.

11. C. Cattell, M.K. Hudson, R.L. Lysak, M. Temerin, R.B. Torbert and F.S. Mozer, "Measurements of Mechanisms Associated with Low Altitude Auroral Particle Acceleration by the S3-3 Satellite", EOS, 60, 346, 1979.

12. M. Temerin, and F.S. Mozer, "The Small Scale Structure of Electrostatic Shocks, American Geophysical Union Meeting", EOS, 60, 346, 1979.

13. C. Cattell, R.B. Torbert, and F.S. Mozer, "The Relationship of Field-Aligned Currents to Plasma Convection Boundaries", EOS, 60, 349, 1979.

14. R.L. Lysak, C. Cattell, M.K. Hudson and M. Temerin, "Energy Flow and Dissipation in the Auroral Zone", EOS, 60, 352, 1979.

NR 323-006, University of California/Los Angeles, "Magnetospheric Substorms", P.I.-Drs. R. L. McPherron and P. J. Coleman, Jr., (213) 825-1882, N00014-75-C-0396

This research program is investigating what triggers geomagnetic storms, how they evolve in time and space, and what controls the magnitude of the disturbance. Ground and satellite magnetometer data are used to monitor micropulsations and electric currents in the magnetosphere and ionosphere during magnetic substorms. The formation of partial ring currents and its relationship to solar wind parameters and the relationship between magnetic micropulsations and triggering substorms is investigated. Progress: It was discovered that Pi2 micropulsations observed in the midnight sector at geosynchronous orbit are always associated with magnetic substorm onsets. It was found that substorms usually have more than one onset. An extremely close relationship between solar wind parameters and Pc3 micropulsations at synchronous orbit has been shown.

Recent Publications:

1. C.R. Clauer and R.L. McPherron, "On the Relationship of the Partial Ring Current to Substorms and the Interplanetary Magnetic Field", J. Geomag. Geoelectr., 30, 195-196, 1978.

2. R.L. McPherron, "Magnetospheric Substorms, Rev. of Geophys. and Space Phys., 17(4), 657-681, 1979.

3. R.L. McPherron, "Magnetic Variations During Substorms", Dynamics of the Magnetosphere, ed. S.I. Akasofu, Reidel, Dordrecht, Holland, 1979.

4. [illegible] Southwood, and W.F. Stuart, "Pulsations at the Substorm Onset", IGPP Pub. #1[illegible], University of California, Los Angeles, October 1978.

5. C.R. Clauer and R.L. McPherron, "Predicting Partial Ring Current Development", IGPP Pub. #1893, University of California, Los Angeles, November 1, 1978.

6. C.R. Clauer, R.L. McPherron and M.G. Kivelson, "Uncertainty in Ring Current Parameters Due to the Quiet Magnetic Field Variability at Midlatitudes", IGPP Pub. #1958, University of California, Los Angeles, August 1979.

7. T. Sakurai and R.L. McPherron, "Satellite Observations of Pi2 Activity at Synchronous Orbit", EOS, 60, 359, 1979.

NR 323-009, Stanford University, "Solar Activity", P.I.-P. A. Sturrock, (415) 497-1438, N00014-75-C-0673

This program of research into solar activity aims primarily at understanding the origin of solar radiation of all types, especially the radio emission and ionizing radiation (EUV and x-ray) which is produced by active regions either continuously or during flares. Several topics are currently under study. We are investigating the role of dynamics in active region coronal loops. A numerical model is being developed to simulate the response of coronal plasma to changes in the coronal heat input. In addition, this model will be modified to calculate the nonlinear effects of thermal instability, which is believed to be important in the lower transition region. Recent observations indicate that the differential emission measure of compact flares has a very strong dependence on temperature. We are investigating whether a model for the flare cooling process which involves supersonic condensation velocities can account for the observations. Also in connection with flares, we are examining possible theoretical models to explain the observed periodicities in the radio microwave and hard x-ray emission. The solar differential rotation is believed to be the primal energy source for most solar activity. We are statistically analyzing long time series of various indices of solar activity to search for any periodicity at 12 days; this period has been predicted for the sun's internal rotation. Progress: The stability of coronal loops has been investigated using a normal mode analysis. It was found that the lower transition region is thermally unstable (Antiochos, 1979). A numerical model for flare loops has been developed and used to predict the evolution and emission of the flare decay phase. From these results it was concluded that e en compact flares have a multi-loop structure (Antiochos and Krall 1979) and that active prominences can be understood in terms of radiatively cooling flare plasma (Antiochos 1980). The differential emission measure of the flare transition region has been determined for the physical situations in which evaporation (Antiochos and Sturrock 1978) dominates the cooling. Daily sunspot numbers for the years 1849 to 1970 have been analyzed, and a period corresponding to synodic rotation of 12.0715 days has been found (Knight, Schatten and Sturrock 1979). A similar period has been found in 10 cm radio flare data.

Recent Publications:

1. "Evaporative Cooling of Flare Plasma", S.K. Antiochos and P.A. Sturrock, Ap. J. 220, 1137, 1978.

2. "The Stability of Solar Coronal Loops," S.K. Antiochos, Ap. J. (Letters), 232, L125, 1979.

3. "The Evolution of Soft X-Ray Emitting Flare Loops", S.K. Antiochos and K. Krall, Ap. J. 229, 788, 1979.

4. "A Sunspot Periodicity and Its Possible Relation to Solar Rotation," J.W. Knight, K.H. Schatten and P.A. Sturrock, Ap. J. (Letters) 224, L153, 1979.

5. "A Model of Active Prominences," S.K. Antiochos, Ap. J. (in press, Feb. 15), 1980.

NR 323-016, University of Washington, Seattle, "Determining the Earth'a Magnetospheric State from Cosmic Ray Anisotropies", P.I. - Dr. J. T. A. Ely, N00014-77-C-0392

There is indirect evidence that connection of a southward interplanetary magnetic field to the geomagnetic field may trigger magnetic storms either through increased entry of solar wind particle flux, through stimulated field line reconnection, or some combination. This experiment will measure the change in geomagnetic configuration due to connection by detecting anisotropies in the galactic cosmic ray flux. If successful, short term forecasts of geomagnetic activity could be possible. Data from the ONR-305 experiment on the S3-4 satellite will be analyzed and correlated with the interplanetary magnetic field, geomagnetic indices, and spacecraft charging events. Progress: The ONR-305 experiment was successfully flown, and collected over 6 months of data.

Recent Publication:

1. John T. A. Ely, "Equatorial Modulation and North-South Assymmetry of Galactic Cosmic Rays Due to the Interplanetary Magnetic Field", J. Geophys. Res. 82, 3643, 1977.

NR 323-031, Cornell University, Ithaca, New York, "Experimental and Theoretical Study of Waves and Irregularities in the Earth'a Ionosphere," P.I. - Dr. M. C. Kelley, (607) 256-7425, N00014-75-C-0780

Radio communication through the ionosphere is known to be disturbed even when a very high frequency is selected for transmission. The disturbances result from plasma density fluctuations in the ionosphere which cause both amplitude and phase scintillation. Although the plasma density fluctuations cannot be eliminated, they can be understood in terms of predicting their time and place of occurrence, of predicting their effect on high frequency transmissions, and of developing a model which quantitatively reflects in situ and remote sensing of the density fluctuations. Parts of this problem are relatively easy to solve such as time and place of occurrence. However, the remainder of the problem requires a sophisticated attack at many levels. Our role is to provide an interpretation of basic plasma measurements from spacecraft such as S3-3 and to fit these measurements into a theoretical framework. Additionally we review the entire problem on a scientific basis and provide those results for our colleagues. In the coming year we will continue analyzing S3-3 plasma wave data of high latitude turbulence anc continue developing an integrated model of spread-F turbulence at the equator. We are also developing a digital plasma wave analysis system to speed our data reduction. Progress: Three review papers have been published supporting an integrated view of spread-F as a hierarchy of processes, each depending on the previous process. The pathways begin with an inverted density distribution in the equatorial ionosphere. Bubbles form at the inversion, rise rapidly upwards, and excite the Kelvin-

Jelmholtz instability. The latter process spreads the density perturbations to smaller wavelengths. At the same time instabilities arise on the sharp density gradient of the bubble producing even shorter wavelength irregularities. At high latitudes much different processes occur. We have recently discovered electrostatic hydrogen cyclotron waves with density perturbations of 10% and wavelengths of 100 meters or less. Further the waves are directly associated with energetic ion beams. We plan to continue studying the energetics of this phenomena.

Recent Publications:

1. Basu, S., and M. C. Kelley, "A Review of Recent Studies of Equatorial F Region Irregularities and Their Impact on Scintillation Modeling," Radio Science, 1979, in press.

2. Costa, E., and M. C. Kelley, "On the Role of Steepened Structures and Drift Waves in Equatorial Spread F," J. Geophys., 83, 4359, 1978.

3. Costa, E., and M. C. Kelley, "Linear Theory for the Collisionless Drift Wave Instability Near the Ion Gyroradius," J. Geophys. Res., 83, 4365, 1978.

4. Fejer, B. G., and M. C. Kelley, "Ionospheric Irregularities," Reviews of Geophysics and Space Physics, 1979, in press.

5. Kelley, M. C. and E. Ott, "Two Dimensional Turbulence in Equatorial Spread F," J. Geophys. Res., 83, 4369, 1978.

NR 323-039, Stanford University, "VLF/ELF Propagation and Wave Induced Precipitation Effects", P.I. - Prof. Robert A. Helliwell, (415) 497-3582, N00014-76-C-0689

This research project investigates: (1) the transionospheric propagation of VLF waves; (2) the nonlinear interaction of these waves with magnetospheric plasma which causes amplification of the VLF wave while causing energetic electron precipitation; (3) the effects of these precipitated particles on VLF and ELF waves propagating in the earth ionospheric waveguide; (4) the generation of electromagnetic waves in the magnetosphere; and (5) the utilization of VLF wave dispersion and raytracing to measure properties of the magnetospheric plasma. Progress: Propagation analysis of super whistlers, that is, whistlers propagating above the cutoff frequency, indicates that after a magnetic disturbance, the magnetospheric plasma distribution shifts from one of diffusive equilibrium to one closer to collisionless. Measurements of plasmapheric densities and of magnetospheric plasma flow, which usually assume diffusive equilibrium, may be in error following magnetic disturbance.

Recent Publications:

1. Bernhardt, P. A., "Theory and Analysis of the Super Whistler," J. Geophys. Res. 84, 5131, 1979.

2. J. P. Luette, C. G. Park, and R. A. Helliwell, "The Control of the Magnetosphere by Power Line Radiation", J. Geophys. Res. 84, 2657, 1979.

3. R. A. Helliwell and U. S. Juan, "A Proposed Mechanism of VLF Discrete Emission Triggering in the Magnetosphere", EOS, 60, 926, 1979.

4. R. A. Helliwell, D. L. Carpenter, and J. P. Katsufrakis, "Initial Results from a VLF Direction Finding Receiver Operated at L=2.3 in the Antarctic", EOS, 60, 347, 1979.

NR 323-042, Lockheed Palo Alto Research Laboratory, "Plasma Interaction Experiment", P.I. - Dr. J. B. Reagan, Dr. W. L. Imhof, Dr. R. D. Sharp, Dr. R. G. Johnson, Dr. S. M. Kaye, Dr. H. D. Voss, Mr. R. W. Nightingale and Mr. E. E. Gaines, (415) 493-4411, ext. 45733, N00014-76-C-0444

This task specifically deals with the measurements and analysis of the energetic electron environment in the outer magnetosphere with the SC-3 spectrometer aboard the P78-2 (SCATHA) spacecraft which was launched on 30 January 1979. Detailed energy spectra are being measured over a broad energy range from 50-5100 keV and fine pitch angle distributions (3° FWHM) in the vicinity of the loss cone are being successfully obtained. Companion wave and magnetic field measurements on the satellite will be available to study the physics of the wave-particle interactions. The other principal aspect of the data in the 0.1 to 32 keV per unit charge range as measured with the SC-8 ion mass spectrometer. SCATHA is the first satellite to provide an extensive data set on the pitch angle distributions of the different ionic species in the synchronous altitude region. Approach in FY 80: The SC-3 and SC-8 data which is just becoming available on computer-compatible magnetic tape will be analyzed in conjunction with the pitch angle and wave data for specific events of interest. Correlations of the precipitation measured by the SC-3 spectrometer with the low altitude P78-1 satellite and other measurements of precipitation, such as on balloons, will be attempted in an effort to understand the precipitation mechanism along geomagnetic field lines. Correlative studies of the composition of the storm time ring current utilizing simultaneous mass spectrometer data from a number of spacecraft will be pursued. Results obtained will be published in appropriate scientific journals. Progress: Principal progress in the period 1 October 1978 to 30 September 1979 relates to the successful launch and on-orbit operation of the SC-3 and SC-8 spectrometers on the P78-2 spacecraft. The performance of the spectrometers has been carefully calibrated on-orbit on a routine basis and they have been found to be operating completely within the expected specifications. Excellent spectral data for the energetic electrons are being routinely obtained with SC-3. A wide variety of pitch angle distributions with fine resolution have been identified including those having (1) empty loss cones, (2) full loss cones, i.e. precipitation, and (3) multiple peaks due to L-shell splitting and temporal changes in the geomagnetic field. The composition of plasma in the energy range of the SC-8 spectrometer has been found to be dominated by H^+ and O^+ ions in the data examined to this time. The O^+ can be taken as the signature of an ionospheric source mechanism while the H^+ can originate from either the ionosphere or the solar wind. Spectral comparisons of the H^+ and He^{++} components allow an inference of the magnitude of the solar wind source. During the magnetic storms examined so far the ionospheric source is often dominant. Conical and field aligned angular distributions characteristic of different classes of ionospheric acceleration mechanisms have been observed.

Recent Publications:

1. "Outer Zone Energetic Electron Spectral Measurements", J. B. Reagan, R. W. Nightingale, E. E. Gaines and W. L. Imhof, paper presented at the Spring 1979 Meeting of the American Geophysical Union, Washington, D.C., EOS, 60,

361, (1979).

2. "The Energetic Electron Environment in the SCATHA Orbit", J. B. Reagan, R. W. Nightingale, H. D. Voss, E. E. Gaines, G. T. Davidson and W. L. Imhof, to be presented at the Fall Meeting of the American Geophysical Union, San Francisco, California, EOS, 60, (in press), (1979).

3. "Outer Zone Energetic Spectral Measurements", J. B. Reagan, R. W. Nightingale, E. E. Gaines, W. L. Imhof and E. G. Stassinopoulos, to be presented at the American Institute of Aeronautics and Astronautics (AIAA) 18th Aerospace Sciences Meeting, January 1980, Pasadena, California.

4. "Hot Plasma Composition Measurements Aboard the SCATHA Satellite", S. M. Kaye, R. G. Johnson, E. G. Shelley and R. D. Sharp, to be presented at the Fall Meeting of the American Geophysical Union, San Francisco, California, EOS, 60, (in press), (1979).

5. "Multiple Satellite Observations of the Hot Plasma Composition During the 21-22 February 1979 Geomagnetic Storms", R. G. Johnson, O. W. Lennartson, R. D. Sharp, E. G. Shelley, H. Balsiger, P. Eberhardt, J. Geiss and D. T. Young to be presented at the Fall Meeting of the American Geophysical Union, San Francisco, California, EOS, 60, (in press), (1979).

6. "Multiple Satellite Observations of the Hot Plasma Composition During the 21-22 February 1979 Geomagnetic Storms", R. G. Johnson, O. W. Lennartson, R. D. Sharp, E. G. Shelley, H. Balsiger, P. Eberhardt, J. Geiss and D. T. Young, to be presented at the First International Symposium on IMS Results, Melbourne, Australia, 30 November 1979.

7. "SCATHA Observations of Hot Plasma Composition", R. G. Johnson, R. D. Sharp and E. G. Shelley, to be presented at AIAA Spacecraft Charging Symposium, Pasadena, California, January 1980.

NR 323-044, University of California, Los Angeles, "Magnetospheric Substorms", P.I. - Dr. P. J. Coleman, (213) 825-1776, N00014-77-C-0343

An understanding of the triggering mechanisms, evolution, location, extent and magnitude of geomagnetic storms can lead to the ability to predict the occurrence of magnetic storms and their effects on Naval electromagnetic systems. An improved ground magnetometer will aid studies on geomagnetic phenomonology. A self zeroing triaxial fluxgate magnetometer and digital data handling system is being designed, fabricated and tested. Progress: A prototype has been fabricated and is undergoing complete end to end testing.

Recent Publications: None

NR 323-047, Stanford University, "A Study of Artificial Modification of VLF Propagation Characteristics," P.I. - Dr. A. V. Da Rosa, (415) 497-3672, N00014-77-C-0586

The release of polyatomic chemicals into the ionosphere, whether intentional or unintentional through rocket exhaust, can, by enhancing recombination, cause depletion in plasma density to occur. The objective of this study is to determine

the effects on VLF wave propagation, which may include enhancement of VLF plasmapheric duct propagation, or disruption of waves propagating in the earth-ionosphere waveguide. The propagation of VLF waves through theoretical simulations of ionospheric depletion is being investigated using raytracing and/or full wave analysis. Archived VLF signal recordings during satellite launches are being searched to identify possible perturbations caused by rocket exhaust. Active modification experiments are being planned for Spacelab-2 over the conjugate point to the Siple VLF transmitter. Progress: A model of three dimensional expansion of neutral gasses in a nonuniform chemically reactive medium that includes thermal and altitude dependent wind effect was developed. Propagation modeling has demonstrated that ionospheric holes produce strong defocusing and multipath fading of VLF waves.

Recent Publications:

1. Bernhardt, P. A. "Three dimensional time dependent modeling of neutral gas diffusion in a nonuniform, chemically reactive atmosphere," J. Geophys. Res. 84, 793-1979.

2. Anderson, D. A. and P. A. Bernhardt, "Modeling the effects of an H_2 gas release on the equatorial ionosphere," J. Geophys. Res. 83, 4777, 1978.

3. Bernhardt, P. A., A. V. Da Rosa, and M. Mendillo, "High Latitude Releases from the Space Shuttle," EOS, 59, 1162, 1978.

NR 323-049, McDonnell Douglas Astronautics Co., "Charged Particle Acceleration in the Inner Magnetosphere," P.I. - Dr. William P. Olson (714) 896-4368, N00014-78-C-0215

Precipitating particles, originally of solar wind origin, are accelerated by more than an order of magnitude within the magnetosphere. The purpose of this study is to investigate the processes responsible for this acceleration, and which are not currently understood. An understanding of these processes is required to successfully develop a dynamical physical model to predict the occurrence and effects of geomagnetic disturbances. The sophisticated model of the geomagnetic field developed previously by this group will be used to quantitatively determine the acceleration and energization of charged particles caused by the time varying magnetic field associated with magnetospheric substorms. The mapping of ionospheric electric fields to the magnetosphere will also be investigated as a possible trigger mechanism. Progress: It was found that the electric field induced by the diurnal wobble of the earth's dipole field can induce potentials as large as 13 kilovolts between the ionosphere and geosynchronous orbit.

Recent Publications:

1. W. P. Olson and K. A. Pfitzer, "The Representation of Time Varying Electric Fields," EOS, 60, 350, 1979.

2. W. P. Olson, K. A. Pfitzer, and G. J. Mroz, "Charged Particle Acceleration in the Inner Ionosphere," Final Report, N00014-78-C-0215, March 1979.

NR 323-051, University of Washington, "Auroral X-ray Imaging," P.I. - Prof. George K. Parks, (206) 543-0953, N00014-78-C-0333

The objective of our research is to study the particle acceleration and precipitation phenomena in natural large-scale, collisionless, magnetized plasma. The earth's outer Van Allen radiation belt provides a convenient place for this study. During magnetospheric substorms, both trapped and precipitated fluxes are enhanced. Our task has been to examine the precipitated energetic electron component by detecting the atmospheric bremsstrahlung X-rays from high-altitude balloons. To study the electrons $\gtrsim$ 22 keV, we have developed an X-ray imaging camera to separate the spatial from true temporal variations in precipitated fluxes. One of our main objectives is to differentiate the plasma acceleration processes active at lower altitudes from those that are active in more distant regions of the magnetosphere. Progress: An X-ray camera was launched on a balloon from Thompson, Manitoba, Canada, on 19 September 1979. Upon reaching the ceiling altitude of about 4 gms/cm^2 atmospheric depth, the camera encountered intense bursts of X-rays in association with the auroral breakup. Preliminary results show that a small precipitation scale ($\sim$10 km) of the energetic component was present during most of the X-ray enhanced period and that precipitating energy spectra varied from one region of the sky to the next.

Recent Publications:

1. "Auroral X-ray Images," Mauk, B., J. Chin, C. Gurgiolo, and G. K. Parks, submitted to J. Geophys. Res., November 1979.

NR 323-056, National Oceanic and Atmospheric Administration, "Coordinated Analysis of Electric Field Data from the S3-3 Satellite," P.I. - Dr. Robert H. Manka, (202) 632-5944, N00014-79-F-0060

Electric Field data from the ONR 104 experiment on the S3-3 Spacecraft will be analyzed and compared with simultaneous data from experiments on the GEOS and other spacecraft and from ground sensors such as a magnetometer arrays. Progress: Data from S3-3 was correlated with various other sources of data collected through the International Magnetospheric Studies Program. The results were presented at the International Magnetospheric Studies Program.

Recent Publications: None

the effects on VLF wave propagation, which may include enhancement of VLF plasmapheric duct propagation, or disruption of waves propagating in the earth-ionosphere waveguide. The propagation of VLF waves through theoretical simulations of ionospheric depletion is being investigated using raytracing and/or full wave analysis. Archived VLF signal recordings during satellite launches are being searched to identify possible perturbations caused by rocket exhaust. Active modification experiments are being planned for Spacelab-2 over the conjugate point to the Siple VLF transmitter. Progress: A model of three dimensional expansion of neutral gasses in a nonuniform chemically reactive medium that includes thermal and altitude dependent wind effect was developed. Propagation modeling has demonstrated that ionospheric holes produce strong defocusing and multipath fading of VLF waves.

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Recent Publications:

1. W. P. Olson and K. A. Pfitzer, "The Representation of Time Varying Electric Fields," EOS, 60, 350, 1979.

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Electric Field data from the ONR 104 experiment on the S3-3 Spacecraft will be analyzed and compared with simultaneous data from experiments on the GEOS and other spacecraft and from ground sensors such as a magnetometer arrays.
Progress: Data from S3-3 was correlated with various other sources of data collected through the International Magnetospheric Studies Program. The results were presented at the International Magnetospheric Studies Program.

Recent Publications: None

SYSTEM THEORY

NR 375-002, University of California, Los Angeles, "Communication Systems Performance", P.I. - Professor K. Yao, (213) 825-2240, N00014-76-C-0875

As modern electronic and communication systems become more complicated and their spplications become more sophisticated, the task of evaluating and optimizing system performances also becomes more demanding. In this research period, our study dealt with practical applications of various new analytical techniques to the evaluation of error probability and the evaluation and design of digital filters and digital signal processing algorithms for communication systems. Progress: We originated the concept of a moment space bounding technique for evaluating tight upper and lower bounds on error probability. In this period, we applied this technique to the evaluation of the performance of practical non-linear satellite systems. We also obtained new and efficient computational algorithms for the use of multi-dimensional moment space error bounds. These results are computationally more efficient and tighter than previously known bounds. Presently, we are studying the application of these techniques to fading and multi-path communications systems as well as some basic geometry of moment spaces. In the digital signal processing area, we obtained realizations for minimum round-off noise in digital filters with practical constraints. We obtained results on various digital detector implementations and associated error probability. By using the branch-and-bound principle, we obtained optimum multiplication-free linear mena-square estimation algorithms. These solutions are of practical interest for real-time and on-board signal processing tasks where high-speed and performance requirements are demanded. We are presently working on applying this technique to efficient FIR and IIR digital filter designs.

Recent Publications:

1. K. Yao and L.B. Milstein, "Performance of PSK Systems with Bandpass Limiters", Proc. 16th Ann. Allerton Conf. on Communication, Control and Computing, Vol. 16, (Oct. 1978) 423-431.

2. T.Y. Yan and K. Yao, "On Minimum Linear Mean-Square Estimation With No Multiplication", Proc. 16th Ann. Allerton Conf. on Communication, Control and Computing, Vol. 16 (Oct. 1978) 99-106.

3. K. Yao, "On Minimum Round-Off Noise Second-Order Digital Filter with Practical Constraints", Proc. Intl. Telemetering Conf., Vol. 14 (Nov. 1978) 1029-1036.

4. S. Reisenfeld and K. Yao, "An Analysis of the Error Probability of an All Digital Detector", Proc. AGARD Conf. on Digital Communications in Avionics, Vol. 239 (June 1979) 29.1-29.13.

5. T. Y. Yan and K. Yao, "Branch-and-Bound Technique Applied to the Solution of Optimum Multiplication-Free Linear Mean-Square Estimator", Abstracts, 1979 IEEE Intl. Symp. on Information Theory (June 1979) p. 62.

6. K. Yao and E. Biglieri, "Multi-Dimensional Moment Error Bounds for Digital Communication Systems", Abstracts, 1979 IEEE Intl. Symp. on Information Theory, (June 1979) p. 110.

7. S. Reisenfeld and K. Yao, "The Computational Cut-Off Rate for a Class of Digitally Implemented Detectors", Abstracts, 1979 IEEE Intl Symp. on Information Theory (June 1979) pp 120-121.

8. A. Gersho, "Asymptotically Optimal Block Quantization," IEEE Trans. Inform. Theory, IT-25 (1979) 373-380.

NR 375-011, University of Tennessee, Knoxville, "Measures of Systems Structural Content," P.I. - R. C. Gonzalez and M. G. Thomason (615) 974-2579, (615) 974-5067, N00014-78-C-0311

Objective: Develop measures of structural content of digital systems which can be useful in establishing relative measures of complexity as they relate to analyzing, testing, and implementing these systems. Progress: Attention is being presently focused on digital switching systems and their representation in the form of binary decision diagrams, which may be viewed as decision trees. It has been shown that the normalized path entropy of these trees is bounded by quantities that depend on the number of variables. Bounds for composite trees have been derived and computational procedures developed for obtaining entropy directly from a given diagram. In addition, the concept of activity of a variable was introduced and a basic theorem was proved which relates this concept to the expected testing cost of the most general type of decision trees. This result was then extended to trees with cycles and to the development of a selection rule for constructing decision trees. The intrinsic cost of general recursive functions was also defined as a measure of testing complexity. Future Work: Work during the coming year will be focused on the development of algorithms for the construction of compact trees with low entropy values. These results and those related to the activity of variable will be extended to the area of fault tree analysis in order to develop measures of system testability, reliability, and maintainability.

Recent Publications:

1. M. G. Thomason, R. C. Gonzalez, and B. M. E. Moret, "Bounds on Tree-Path Entropy", Technical Report TR-EE/CS-79-10, Electrical Engineering Department, University of Tennessee, Knoxville, June, 1979. (Under review by IEEE Trans. on Computers).

2. B. M. E. Moret, M. G. Thomason, and R. C. Gonzalez, "The Activity of a Variable and its Relation to Decision Trees", Technical Report TR-EE/CS-79-40, Electrical Engineering Department, University of Tennessee, Knoxville, October, 1979. (Under review by Communications of the ACM).

NR 375-013, Old Dominion University Research Foundation, Norfolk, "Cumulant Control and Estimating Systems", P.I. - S. R. Liberty, (804) 440-3741, N00014-78-C-0443

Complete statistical descriptions of Linear Quadratic Gaussian systems are being studied with the objective of establishing design procedures for control and estimation systems according to criteria more general than minimization of ensemble average performance. This research is in its final phase with the current effort being concentrated on the cumulant class of problems. Progress: The major result of the FY 79 research effort was the solution of a general feedback control problem in the cumulant class. The solution exhibits the classical separation property of LQG control and is characterized by linear dynamical feedback of fixed point (causal) smoothed estimates of the plant

state. A manuscript reporting this result is in preparation.

Recent Publications:

1. "Performance Measure Statistics for Discrete Time Stochastic Linear Control System Design", S. R. Liberty and C. R. Parten, Proc. of Twelfth Annual Asilomar Conference on Circuits, Systems and Computers, Vol. 12, pp. 292-293, November 1978.

2. "Design-Performance-Measure Statistics for Stochastic Linear Control Systems", S. R. Liberty and R. C. Hartwig, IEEE Transactions on Automatic Control, Vol. AC-23, No. 6, pp. 1085-1090, December 1978.

NR 375-014, University of Notre Dame, "Fault Diagnosis of Large-Scale Analog Systems - A Tearing Method Approach," P.I. - Dr. Ruey-wen Liu, (219) 283-6228, N00014-78-C-0444

The development of new approaches for the fault analysis of large electronic circuits is the main scope of this research work. There are two main objectives: the development of a fault directory approach to the fault isolation problems, and the development of a stochastic process approach to fault prevention problems. Progress: Two new concepts have been developed and reported. The concept of accessibility is concerned with a measure on how deep in a cricuit one can probe from the outside measurements. Also, the concept of sequentially linear diagnosibility concerning the reduction of computation cost, by a proper design of the locations of test points of a given circuit, has been developed. A significant progress has been made recently in the development of a fault directory approach to fault isolation problems. The major obstacles have been identified and methods have been developed to circumvent them. The phase of the development of a stochastic process approach to the fault prevention problem is new, (originated June 1979.) Certain kinds of faults can be prevented if techniques can be developed to estimate the location and the characteristics of noise sources of a given circuit. Some progress has been made for linear circuits.

Recent Publications:

1. R. Liu and V. Visvanathan, "Sequentially Linear Fault Diagnosis: Part I - The Theory," IEEE Trans. on Circuits and Systems, (A Special issue on Automatic Analog Fault Diagnosis), PP. 490-495, July 1979.

2. V. Visvanathan, and R. Liu, "Sequentially Linear Fault Diagnosis: Part II - The Design," Ibid, pp.558-564, July 1979.

3. R. Liu, V. Visvanathan and C. Lin, "Tearing in Fault Diagnosis," IEEE International Symposium on Circuits and Systems, pp. 874-877, July 1979.

4. C. S. Lin and R. Liu, "A Single-Fault Diagnosis Theory," Allerton Conference on Communications, Control and Computation, October 1979.

5. E. Fogel, "On Strong Consistency of Some Adaptive Alogrithms," Allerton Conference on Communication, Control and Computation, October 1979.

Thesis:

1. Y. F. Huang, "System Identification Using Membership Set Description of System Uncertainties," M. S. Thesis, (Advisor: E. Fogel), University of Notre Dame, Notre Dame, Indiana, September 1979.

NR 375-015, California Institute of Technology, Pasadena, "Electronic Power Systems", P.I. - Dr. Slobodan Ćuk, (213) 795-6811 ext. 2492, N00014-78-C-0757

Electronic power processing emerged in the last decade from the need to find better and more efficient ways for the conversion and regulation of the prime electric power. A great variety of switching structures have been proposed in the past to perform a multitude of functions: dc-to-dc conversion, dc-to-ac inversion, ac-to-dc controlled rectification and power amplification. The fact that different topological interconnections of the same components (storage elements and switches) can lead to markedly different results in terms of efficiency, switching ripple, dynamic response and overall performance, motivated the fundamental investigation of the topological properties of switching structures. A search was initiated for the most general topological correlation among the known switching converter configurations as well as for a general method which will facilitate the discovery of new, as yet unknown converter configurations, and culminate in an optimum topology. Progress: Major progress has been made by establishing *duality* to be the most general topological correlation among switching dc-to-dc converters, appropriately modified to include current driven converters as well. The basic buck and boost converters, previously considered topologically unrelated, are shown to be dual to each other. The new optimum topology converter is obtained by duality transformation application on the conventional buck-boost converter. A new mode of switching converter operation, termed discontinuous capacitance voltage mode is discovered. The application of duality to other converter configurations and extension to functionally different switching power amplifier configurations is currently in progress.

Recent Publications:

1. Slobodan Ćuk, "General Topological Properties of Switching Structures," IEEE Power Electronics Specialists Conference, 1979 Record.

2. R. D. Middlebrook, "Modelling and Design of the Ćuk Converter," Proc. Sixth National Solid-State Power Conversion Conference (Powercon 6), pp. G3.1-G3.14, May 1979.

3. Loman Rensink, Art Brown, Shi-Ping Hsu, and Slobodan Ćuk, "Design of a Kilowatt Off-Line Switcher Using a Ćuk Converter," Proc. Sixth National Solid-State Power Conversion Conference (Powercon 6), pp. H3.1-H3.26, May 1979.

4. Shi-Ping Hsu, Art Brown, Loman Rensink, and R. D. Middlebrook, "Modelling and Analysis of Switching Dc-to-Dc Converters in Constant-Frequency Current-Programmed Mode," IEEE Power Electronics Specialists Conference, 1979 Record.

NR 375-018, University of Minnesota, "Essential Pattern and Sequence Sensitivity in Semiconductor Memories", P.I. - Dr. Al Tuszynski, (612) 373-2970, N00014-78-C-0741

Some soft errors are attributable to random environmental perturbations such as cosmic rays, for example, and some are merely a metter of specsmanship. Both are relatively benign. Infrequent, discrete, random errors can be dealt with by recourse to error-correcting techniques, while specification improprieties can be eliminated through proper identification of worst-case conditions. A third category, not so benign, arises because of marginalities precipitated by process variations and circuit-design flaws. One can quantize the risk of this category of errors, but only by reference to process statistics. It is the purpose of this project to provide the relevant statistics of "one-transistor" RAMs. Progress: New tools have been developed for the evaluation of evanescent circuit phenomena. A patent application has been filed for a probe whose static and dynamic impedances are high enough to permit measurement of 10 ns rise-and-fall times on 1 pF stand-alone capacitors. The concept of pseudoanalog testing has been demonstrated to give reliable estimates of reference and storage capacitances of 16k-RAMs. The arguments for minimal testing of RAMs have been popularized through articles and verbal presentations.

Recent Publications:

1. A. Tuszynski, "Self Learning Machines Applied to the Testing of Semiconductor Memories", IEEE Autotestcon 1978, pp. 246-250.

2. Eckhard Wolfgang, "Electron Beam Testing of VLSI Circuits", IEEE JSSC, April 1979, pp. 471-481.

NR 375-019, Naval Postgraduate School, "Reduced Order Characteristics of Circuits and Systems", P.I. - Dr. Sydney R. Parker, (408) 646-2788/2082, N0001480WR00038

The purpose of this research is to investigate techniques for the macroscopic modeling of linear and nonlinear circuits and systems for purposes of fault detection and performance evaluation. The macroscopic model parameters are to be developed dynamically from a finite set of input/output measurements on the circuit/systems. The techniques being investigated are significant in light of the developing technology in very large scale integrated circuit (VLSI) technology which can be expected to expand on-line computational capabilities well beyond what is available today. Progress: This is a new project. However, the following progress can be reported: As a result of linear model studies using an equation error formulation, the coefficients of the denominator of a general zero/pole (ARMA) model have been related to the coefficients of the all pole (AR-auto regressive) model, and the coefficients of the numerator of a general zero/pole model have been related to the all zero (MA-moving average) model coefficients. This formulation enables a full set of model parameters, ranging from the all pole through the mixed zero/pole to the all zero models, to be obtained readily from measured data. As an extension of the foregoing linear studies a generalized discrete nonlinear model has been postulated and tested. This model is based upon the equation error formulation and consists of discrete Volterra like

series expansions for the input and output signals, respectively, and discrete bivariate expansions for cross coupling between input and output signals. Minimizing a quadratic error criteria between the model and system outputs, based upon the equation error, leads to nonlinear model parameter estimation procedures involving the solution of a set of linear equations. The coefficients of these equations involve high order auto and cross correlation functions of the input and output data. Current studies are directed toward model residues (errors) and the lattice type models (reflection factors) to characterize the system. These studies are being extended to include the general nonlinear model.

Recent Publication: A presentation of "Reduced Order Modeling of Analog Circuits" was made at the IEEE 1979 International Symposium on Circuits and Systems, Tokyo. Several papers are presently being prepared.

NR 375-021, University of Pennsylvania, "Microwave Antenna Arrays", P.I. - Dr. Bernard D. Steinberg, (215) 243-6352, N00014-79-C-0505

High angular resolution for imaging systems using phased-array antennas demands a large aperture which, in turn, requires a large number of elements. Practicality, however, demands drastic thinning or frugality in the design of phased arrays for imaging purposes. Research on drastic thinning of arrays has shown that resolvability can be maintained and angular ambiquities (grating lobes or aliasing) eliminated by randomizing the locations of the sample points. It has been found instead that the grating lobe energy becomes uniformly spread, in a statistical sense, throughout the angular domain and, consequently, constitutes an average background level in an image formed by such an array. Because of this backgfound level, the resolving properties of the array are determined not only by the size of the array but also by the range of target or signal strengths that the array is to image. The two subjects for study under this contract,--non-fourier spectral estimation techniques and image background-level reduction techniques--influence the resolution properties of a system, and therefore the image quality. Enhanced resolution in spectral estimation of bandlimited processes using non-fourier techniques, such as maximum entropy processing, maximum likelihood processing, Prony's method of pole extraction, and pencil-of-function method, will be systematically examined for their applicability to the random, thinned antenna array. Reduced peak sidelobes of these arrays, via sidelobe suppression algorithms or local-region peak sidelobe reduction by diversity techniques, will also be investigated. Progress: Prony's method was found to be inappropriate for resolution enhancement when the effects of uncertainties in sample point location are considered. Preliminary results on the maximum entropy technique indicate good promise provided that: (1) the signal-to-noise ratio is large and (2) that only angular resolution, and not accuracy, is demanded of the system. Studies of peak sidelobe reduction in a local region, using amplitude and position diversity, have been conducted; position diversity shows promise.

Recent Publications:

1. Ajay K. Luthra, "Application of Modern Spectrum Analysis Techniques in Space-Angle Domain: Prony's Method," Valley Forge Research Center, Quarterly Progress Report No. 30, August 1979, pp. 57-62.

2. Ajay K. Luthra, "Application of Modern Spectrum Analysis Techniques in Space-Angle Domain: Maximum Entropy Method (MEM)," Valley Forge Research Center, Quarterly Progress Report No. 31, November 1979, pp. 48-57.

3. Ajay K. Luthra, "Effect of Superimposing Power Patterns Obtained by Randomization of Element Weights," Valley Forge Research Center, Quarterly Progress Report No. 31, November 1979, pp. 44-47.

NR 375-023, California Institute of Technology, "Submicron System Architectures", P.I. - Prof. Ivan E. Sutherland, (213) 795-6841, N00014-79-C-0597

The technical objective of this research is to provide fundamental advances in the areas of design methodologies, testing, and architectural structures for effectively employing very large scale integration (VLSI) technology to achieve significant advances in high performance Navy electronic systems. These electronic systems will be employed in a wide range of current and projected Navy applications, including intelligence, logistics, command and control, and in weapon systems. The general scientific understanding sought will pay special attention to opportunities for improvements in performance, reliability, testability, and design verification, to methods for achieving self-timing, fault tolerance, and fault isolation, and to problems in the design cycle brought about by the combinatorics of very large scale systems. The approach is to investigate architectures for submicron feature size VLSI systems with the objective of discovering how to employ this technology to achieve computing capabilities far in excess of those available today, and to undertake theoretical studies, simulations, experimental designs, and prototype developments aimed at building a general scientific understanding of the problems and opportunities presented by scaling microcircuit technology to submicron dimensions. Progress: New program

Recent Publications: None

NR 375-024, Research Triangle Institute, "Reliable Digital System Design," P.I. - K. S. Trivedi (Duke University) (919) 684-3048, J. B. Clary, (919) 541-6951, N00014-79-C-0571

Previous approaches to digital system design have emphasized functional performance requirements with little attention given to maximizing system reliability and maintainability. The objective of this research is to explore system design approaches which maximize reliability while meeting baseline performance requirements, subject to cost constraints. Initial emphasis is given to systems with linear storage hierarchies. The problem is to select the capacities of various memory levels in a storage hierarchy. The storage technologies in the hierarchy are linearly ordered by the access times, and the information transfer is between adjacent levels only. The CPU can only access information from the fastest level (e.g., cache). The hierarchy is managed automatically. We study the trade-offs involved in the selection of the memory level capacities using a geometric programming model. The optimization problem is set up with the objective of maximizing system reliability subject to fixed cost and performance constraints. It is shown that any relative maximum of this complex problem is also its global maximum.

Closed form solutions for the capacities are obtained, and an example illustrating the use of our technique is given. It is interesting to note that the resulting system in the example closely resembles a typical PDP 11/60 configuration. Further research will emphasize reliable CPU design approaches. Reliability achieved through fault-tolerant computing techniques will be modeled.

Recent Publications:

1. "Analytic Modeling of Computer Systems," K. S. Trivedi, IEEE Computer, Vol. 11, no. 10, pp. 38-56, October 1978.

2. "Mathematical Models for the Design and Analysis of On-Line Built-In-Test," K. S. Trivedi, Proceedings 1978 Government Microcircuit Applications Conference, November 1978.

3. "A Performance Comparison of Optimally Designed Systems with and without Virtual Memory," K. S. Trivedi with T. M. Sigmon, Proceedings, 1979 International Symposium on Computer Architecture.

4. "A Decision Model for Closed Queuing Networks," K. S. Trivedi with R. A. Wagner, IEEE Transactions on Software Engineering, Vol. SE-9, No. 4, pp. 328-332, July 1979.

5. "Verification of Built-In-Test Performance in Modular Digital Systems Using Instruction Set Processor (ISP) Language Descriptions," J. B. Clary and F. M. Smith, Proceedings of 1979 Automatic Testing Conference, September 1979.

6. "Self-Testing Computers," J. B. Clary and R. A. Sacane, IEEE Computer, Vol. 12, No. 10, pp. 49-59, October 1979.

NR 375-025, Institute for Software Engineering, "Science of Design", P.I. - Kenneth W. Kolence, (415) 493-0300, N00014-79-C-0586

The general scientific problem being addressed in this work is the question: is a "science of design" a viable concept. The objectives of this effort are twofold. The first is to clearly describe those aspects of design which appear to be amenable to the development of a science of design, and to put forth basic criteria which any such science must fulfill. This objective is nearly attained, with only minor analysis remaining before the formal write-up is begun. The second is to fully demonstrate the meaning of these ideas in the context of the computer software design process. In so doing, the intent is equally to demonstrate the feasibility of a more general theory or science of design. The approach in this research is to concentrate on the structural properties of a design description, and to relate these to the properties which arise from the physical realization of the design substructures. In the context of software designs, the initial focus is on developing an adequate morphology of software structures and designs. This is currently the major effort. Subsequent effort then involves methods of properly describing the relationship between structures to achieve the functional software properties desired. Concurrently, software physics theory will be used to quantify

the resource consumption behavior of the realized design. Finally, the work will be integrated into a general software life cycle, and used to consider how the life cycle phases can then be more precisely defined. The project is expected to be completed during this fiscal year. Progress: New

Recent Publications: None

NR 375-026, University of California, Davis, "Development of a Partially Symmetric Architecture for the Simplified Design of Combinational Circuits", P.I. - Dr. Richard Spillman, (916) 752-7390, N00014-79-C-0770

This research investigation proposes to develop an alternative combinational design algorithm which will result in a significant reduction in total lead count and improve the testability of combinational circuits. The algorithm under investigation exploits the partial symmetries of each combinational function to introduce extra don't cares into the functional implementation. The current research effort involves a study of the nature of the symmetry groups of Boolean functions and the development of an optimum design algorithm for partially symmetric combinational functions. Progress: New

Recent Publications: None

NR 375-028, California Institute of Technology, Jet Propulsion Laboratory, "Submicron System Architectures," P.I. - Prof. Carver A. Mead, (213) 795-6841 ext. 2568, N00014-79-C-0924

The technical objective of this research is to substantiate recommendations of the Design, Architecture, Software and Testing (DAST) Committee of DoD's Very High Speed Integrated Circuit (VHSIC) Program, that a simple set of standards and design rules should be adopted for VLSI designs at all levels. The design rules would dictate conventions to which designs must conform, the standards would dictate both a minimum set of design rules and the way in which design rules and designs are represented (documented). The approach is to conduct a small scale demonstration of the effective use of standards, design rules, and interfaces in the separated design and fabrication of VLSI. Specifically, use the design rules, standards, and fabrication-line interfaces being developed under NR 375-023 to: (1) Develop CMOS-SOS and/or NMOS Si gate circuit designs and test chips; (2) Develop design-rule checking software; (3) Develop the Cal Tech Intermediate Form (CIF) Interface Software for APPLICON and CALMA computer-aided design (CAD) graphic systems; and (4) Convert CIF formatted circuit and test chip designs to a format acceptable by the APPLICON and/or CALMA graphic systems. Progress: New program

Recent Publications: None

NR 375-031 (Formerly NR 375-041X), California Institute of Technology, "Solid State Electronics Principles", P.I. - Dr. Carver A. Mead, (213) 795-6841 ext 2568, N00014-76-C-0367

The increasing complexity associated with IC design is already too great for

the human to use traditional approaches to the design of Naval electronic systems. The objective of this research effort is a qualitatively different approach to high complexity IC design that will produce the maximum benefits of this technology in terms of low-design-cost implementations, low power and high speed capabilities, and efficient use of chip area: An approach to a theory of VLSI design is to develop a structured design methodology, for large scale IC's, that facilitates interactive design, and a theory for high complexity IC structures: the composition of large scale structures from substructures and the physics of computational systems. Progress: A computer program--"silicon compiler"--has been constructed that produces a more efficient chip layout from a high level description of the desired machine structure and instruction set. Techniques for delay-time optimization of driver and sense amplifiers on inter- and intra-chip communication paths have been developed to maximize performance of an LSI system. A theory of power distribution on VLSI chips has been worked out. Considerable progress has been made in understanding the fundamental physical nature of computational systems: a somewhat broadened concept of entropy is used to unify the ideas of thermodynamics, information theory, and computation. The structured VLSI design methodology has been introduced into the curriculum of a number of major universities and industrial firms; As a first step towards introducing some commonality in design methodology and notation, the CalTech Intermediate Form (CIF) has been introduced as a universal medium for the interchange of integrated circuit artwork.

Recent Publications:

1. C. A. Mead, "Delay-Time Optimization for Driving and Sensing of Signals on High-Capacitance Paths of VLSI Systems", IEEE J. of Solid-State Ckts., Vol. SC-14, Apr 1979, pp. 462-470.

2. C. A. Mead and L. A. Conway, Intro. to VLSI Systems, Limited Printing, 1978.

NR 375-060, University of Pennsylvania, "Fault Analysis of Analog Circuits," P.I. - Dr. Samuel D. Bedrosian, (215) 243-8518, N00014-75-C-0768

Naval Electronic Systems continue to become more complex. There is increasing urgency to develop equally sophisticated procedures for detection, diagnosis and prediction of system faults. There is compelling need for excellent reliability and maintainability to make possible significant reduction in life cycle costs. Our aim is to make a viable ATE design that takes maximum advantage of inexpensive test equipment and simple computation facilities. Progress: Development of the learning model based on a fuzzy automaton with linear reinforcement continues. Studies underway assess the relative success of alternative criteria to reduce the ambiguities (fuzziness) in the analog fault diagnosis problem. Specific investigations have been made based on a fuzzy distance measure and a fuzzy entropy measure. Both show markedly improved performance compared to the nearest neighbor rule with respect to isolating the most likely faulted component. Further improvements are being sought.

Recent Publications:

1. S. D. Bedrosian and J. H. Lee, "A Fault Isolation Method in Nonlinear Analog Networks Using Fuzzy Set Concepts," Proc. of 12th Asilomar Conference on Circuits, Systems and Computers, November 1978.

2. S. D. Bedrosian, "Analog ATPG: A Response to Users' Needs," Proc. AUTOTESTCON '78, November 1978.

3. S. D. Bedrosian and J. H. Lee, "Application of Fuzzy Set Concepts to Fault Diagnosis," Proc. of the 22nd Midwest Symposium on Circuits and Systems, June 1979.

4. S. D. Bedrosian and J. H. Lee, "Further Results on a Fuzzy Measure Function for Analog Fault Isolation," IEEE International Symposium on Circuits and Systems, Tokyo, Japan, July 1979.

5. S. D. Bedrosian and J. H. Lee, "Fault Isolation Algorithm for Analog Electronic Systems Using the Fuzzy Concept," IEEE Trans. on Circuits and Systems, Vol. CAS-26, July 1979.

6. S. D. Bedrosian and J. H. Lee, "An Application of Fuzzy Measure for Analog Fault Isolation," Proc. of AUTOTESTCON '79, Minneapolis, Minn., September 1979.

NR 375-106, University of California, Berkeley, "Development of Nonlinear Circuit Models for Electronic Devices," P.I. - Professor L. O. Chua, N00014-76-C-0572

This research program covers a wide spectrum of topics in the area of nonlinear circuit and system theory. The main objective is to develop systematic methods for modeling and analyzing complex nonlinear phenomena and properties in modern devices and systems. Modeling of nonlinear devices is presently more art than science. Many years of concerted research will be needed before a unified approach may evolve. Our research in the past year on device modeling has been to develop specific methods for concrete devices where realistic models are presently in dire need. We have succeeded in developing nonlinear circuit models for the IMPATT diode, Gunn diode, and s.c.r. All of these models are derived from device physics and nonlinear circuit synthesis techniques. Future research would involve three areas. The first is to develop nonlinear circuit models for other important 3-terminal devices, such as the GaAs FET. The second is to develop general methods for nonlinear circuit synthesis. The third area is to develop a firm foundation for many nonlinear circuit-theoretic concepts, such as passivity, losslessness, reciprocity, etc., with an aim to establishing the limits of performance of modern devices. Progress: A series of 7 papers has been published during the period 1 Oct. 1978 to 30 Sept. 1979. These papers cover a broad spectrum of topics in nonlinear device modeling and in nonlinear circuit concepts and properties related to modeling and synthesis.

Recent Publications:

1. "A nonlinear lumped circuit model for Gunn diodes," L. O. Chua and Y. W. Sing, International Journal of Circuit Theory and Applications, Vol. 6, pp. 375-408, (October 1978).

2. "A global representation of multidimensional piecewise-linear functions with linear partitions," S. M. Kang and L. O. Chua, IEEE Transactions on Circuits and Systems, Vol. 25, pp. 938-940 (November 1978).

3. "Nonlinear lumped circuit model for SCR," L. O. Chua and Y. W. Sing, IEE Journal on Electronic Circuits and Systems, Vol. 3, pp. 5-14, (January 1979).

4. "The Hopf bifurcation theorem and its applications to nonlinear oscillation in circuits and systems," A. Mees and L. O. Chua, IEEE Transactions on Circuits and Systems, Vol. CAS26, pp. 235-254 (July 1979).

5. "A unified theory of symmetry for nonlinear multiport and multiterminal resistors," L. O. Chua and J. Vandewalle, International Journal of Circuit Theory and Applications, Vol. 7, pp. 337-371 (July 1979).

6. "Frequency domain analysis of nonlinear systems: general theory," L. O. Chua and C. Y. Ng, IEE Journal on Electronic Circuits and Systems, Vol. 3, pp. 165-185 (July 1979).

7. "On the dynamics of Josephson junction circuits," A. A. Abidi and L. O. Chua, IEE Journal on Electronic Circuits and Systems, Vol. 3, pp. 186-200 (July 1979).

NR 375-131, Yale University, "Adaptive Techniques in Communications and Control Theory", P.I. - Dr. K. S. Narendra, (203) 432-4611, N00014-76-C-0017

Conventional control theory deals with the control of dynamical systems whose mathematical representations are completely known. In contrast to this adaptive control addresses the control of partially known systems. The objective of the research is to develop stable adaptive algorithms for identification and control and apply these to appropriate practical problems. Progress: The stable adaptive control of an unknown linear plant has for over twenty years remained an open problem. Recently four solutions were suggested, of which two [1], [2] were achieved at Yale. The principal result assures that the parameters of a controller in Model Reference Adaptive Control will converge to desired values in a stable fashion, regardless of the initial conditions. It is known that the different methods used for the stability analysis of the above problem are equivalent [3]. In particular, it has been shown that two philosophically different approaches - Direct Control and Indirect Control - are equivalent for a particular parametrization of the unknown plant [4]. With the resolution of the stability problem interest in the adaptive area has shifted to adaptive control of multivariable and stochastic systems. At a recent workshop held at Yale,on Applications of Adaptive Control, some of the major areas which need further investigation were discussed.

Recent Publications:

1. "Stable Discrete Adaptive Control," Narendra, K. S. and Lin, Y. H., S & IS Report No. 7901, Yale University [to appear in the IEEE Transactions on Automatic Control].

2. "Stable Adaptive Controller Design - Part II Proof of Stability," Narendra, K. S.; Lin, Y. H. and Valavani, L. S., S & IS Report No. 7904, Yale University [to appear in IEEE Transactions on Automatic Control].

3. "Design of Stable Model Reference Adaptive Controllers," Narendra, K. S. and Lin, Y. H., Proceedings of the Workshop on Applications of Adaptive Control, Yale University, August 1979.

4. "Direct and Indirect Model Reference Adaptive Control," Automatica, Nov. 1979.

5. "Stable Adaptive Controller Design - Direct Control," Narendra, K. S. and Valavani, L. S., IEEE Transactions on Automatic Control, Vol. AC-23, No. 4, pp. 570-583, August 1978.

NR 375-971, Rensselaer Polytechnic Institute, "Detection, Estimation and Filtering in Impulse Noise", P.I. - J. W. Modestino, Electrical and Systems Engineering Department, (518) 270-6324, N00014-75-C-0281

This project has been concerned with the stochastic modeling of both one and two-dimensional impulsive phenomenon and the development, characterization and performance evaluation of various optimum and suboptimum processing structures operating in such environments. In the 1-D case we have been concerned with the development and characterization of explicit impulsive noise models for various communication channels exhibiting impulsive characteristics. This has led to the development of optimum receiver structures whose performance provides a benchmark for assessing the relative performance of various suboptimum receiver structures which are under investigation. In the 2-D case, our interest has been focused on the development of stochastic models for real-world imagery exhibiting predominant and pronounced edge structures. The models have application in such areas as: edge detection, image enhancement, texture discrimination and image coding. Investigations in each of these areas are underway. Progress: Important technical accomplishments during the reporting period have included: (1) A class of 1-D stochastic processes has been developed which includes the random telegraph and random binary waveforms as special cases. More recent efforts have concentrated on the development of more general techniques for the evaluation of the second-order statistics associated with this class of processes. Preliminary results have been obtained describing maximum likelihood (ML) and maximum a posteriori (MAP) estimators of the parameters describing this class of processes; (2) A complete second-order statistical description of the class of 2-D random fields generated by random tessellations of the plane has been developed, which includes not only autocorrelation functions and power spectral densities but also joint probability density functions; (3) A new approach to image enhancement based upon nonlinear 2-D homomorphic filtering concepts has been developed using stochastic models for the signals and degradations; (4) A new approach to the design of the feedback predictor in a 2-D DPCM encoder has been developed, which is based upon an assumed stochastic image model that exhibits the predominant and pronounced edge structure typical of real-world imagery and is in distinction to the conventional approach based upon 2-D autoregressive (AR) modeling assumptions. The resulting DPCM encoder has significant performance advantages over existing DPCM design approaches, and has demonstrated an improved ability to cope with channel errors; (5) A class of nonlinear receiver structures has been extended and refined for application to the detection of weak signals in non-Gaussian narrowband noise. Resulting in a useful class of non-Gaussian narrowband noise models for which the locally optimum receiver structure can be explicitly determined. A rather simple adaptive nonlinear receiver structure has been developed that attempts to adapt to the unknown prevailing noise environment and provides fairly efficient and robust performance in a wide variety of non-Gaussian narrowband noise environments; (6) A generalized narrowband impulsive noise model has been developed that appears useful in a wide variety of impulsive noise situations. The model consists of the sum of a low-density shot noise process and additive white Gaussian noise (WGN), thus representing an important generalization of the impulsive noise

models; (7) A new approach to texture discrimination has been developed and is based upon an assumed stochastic model for texture in imagery and is an approximation to the statistically-optimum maximum-likelihood classifier. The efficacy of this approach has been demonstrated through experimental results obtained with simulated texture data and a comparison has been provided with more conventional texture discriminants under identical conditions; (8) The performance and properties of a particular combined source-channel coding approach has been investigated for the encoding, transmission and remote reconstruction of image data. The source encoder employs a 2-D DPCM coder and the result is a relatively robust design that is reasonably insensitive to channel errors and yet provides performance approaching the rate-distortion bound. The combined source-channel coding approach for images has also been extended to the case where the source encoder employs 2-D block transform coding using the discrete cosine transform (DCT). The approaches developed provide a rationale for combined source-channel coding that provides improved quality image reconstruction without sacrificing transmission bandwidth; and (9) Some preliminary results on the performance and complexity of tree encoding of images in the presence of channel errors have been obtained that demonstrate that performance close to the rate-distortion bound is achievable in the absence of channel errors for synthetic images modeled as 2-D autoregressive random fields and employing the (M,L) algorithm.

Recent Publications:

1. J. W. Modestino and D. G. Daut, "Combined Source-Channel Coding of Images", Proc. of Sixteenth Annual Allerton Conference on Communication, Control and Computing, Urbana-Champaign, Ill., Oct. 1978, pp. 392-402.

2. J. W. Modestino and A. Y. Ningo, "Detection of Weak Signals in Narrowband Non-Gaussian Noise", IEEE Trans. on Inform. Theory, Vol. IT-25, September 1979, pp. 592-600.

3. R. W. Fries and J. W. Modestino, "Image Enhancement by Stochastic Homomorphic Filtering", Proc. of 1979 IEEE International Conference on Acoustics, Speech and Signal Processing, Washington, D. C., April 1979, pp. 650-655.

4. J. W. Modestino, K. R. Matis, K. Y. Jung and A. Y. Ningo, "Digital Simulation of Communication Systems Operating on Fading-Dispersive Channels", IEEE/NUSC Workshop on Communication in Fading-Dispersive Medium, New London, Conn., June 1979.

5. J. W. Modestino and D. G. Daut, "Combined Source-Channel Coding of Images", IEEE International Symposium on Information Theory, Grignano, Italy, June 1979.

6. J. W. Modestino, R. W. Fries and A. L. Vickers, "Stochastic Image Models Generated by Random Tessellations of the Plane", Proc. of NSF/ONR Workshop on Image Modeling, Chicago, Ill., August 1979. Also to appear as chapter in Image Modeling, A. Rosenfeld, Ed., Academic Press.

7. J. W. Modestino, G. R. Redinbo, K. R. Matis, A. L. Vickers and P. K. Leong, "Digital Simulation of Communication Systems", Proc. of 1979 IMACS Congress on the Simulation of Systems, Sorrento, Italy, Sept. 1979.

JOINT SERVICES ELECTRONICS PROGRAM (JSEP)

JOINT SERVICES ELECTRONICS PROGRAM (JSEP) (Dr. J. O. Dimmock, 202-696-4216)

The JSEP is a long-term, broad-based, electronics-oriented multidisciplinary research program supported by the Army Research Office (ARO), the Office of Naval Research (ONR) and the Air Force Office of Scientific Research (AFOSR). The Technical Coordinating Committee which sets policy and guidance currently consists of:

Navy Member - Dr. J. O. Dimmock, ONR
Army Member - Dr. J. R. Suttle, ARO
Air Force Member - Dr. T. Walsh, AFOSR

The FY 1979 program composition is given in the following table:

Institution	Starting Date	Director	Contractor
MIT(RLE)	1945	P. A. Wolff	Army
Harvard	1945	N. Bloembergen	Navy
Columbia (Radiation Lab.)	1946	G. W. Flynn	Army
Stanford (Electronics Lab.)	1947	J. D. Meindl	Army
Stanford (Ginzton Lab.)	1947	M. Chodorow	Navy
Polytechnic Institute of NY	1955	A. A. Oliner	Air Force
Illinois (CSL)	1959	R. T. Chien	Navy
California (Berkeley)	1961	D. J. Angelakos	Air Force
USC	1963	Z. A. Kaprelian	Air Force
Texas (Austin)	1964	E. J. Powers	Air Force
Cal. Tech.	1978	R. W. Gould	Army
Ohio State (ESL)	1978	C. H. Walter	Navy
Texas Tech.	1978	R. Saeks	Navy
Cornell	1979	L. F. Eastman	Air Force
Georgia Tech	1979	D. T. Paris	Army

Individual work units supported under the JSEP are listed below.

University of California, Berkeley: D. J. Angelakos (415) 642-7200)

Investigator	Title
D. J. Angelakos	Multiple Scattering of Conducting Bodies
D. J. Angelakos	Infrared and Optical Antennas and Guides
C. Hu	Lifetime Studies in Ion-Implanted Semiconductors
C. Hu	Compound Semiconductors: Material - Properties and Device Studies
T. E. Everhart	Research in Advanced Lithographic Techniques for Microcircuits
T. Van Duzer	Fundamental Limitations of Miniaturization of Josephson Memory and Logic Circuits
D. A. Hodges	New Integrated Circuit Processes for High-Performance LSI
R. W. Broderson	Basic Research in Wide Dynamic Range Low - Noise Amplification Using Monolithic Integrated - Circuit Technology
S. Wang	Thin-Film and Guided - Wave Active Optical Devices
T. K. Gustafson	Millimeter and Infrared Heterodyne Mixing and Detection
L. O. Chua	Large Scale and Nonlinear Circuits Study
C. A. Desoer	Control of Large Systems
R. G. Meyer	Computer Optimization of Electronic Circuits
A. M. Despain	VLSI Circuits for Future Computing Systems
R. W. Broderson	Analog Adaptive Filters for Speech Processing

California Institute of Technology: R. W. Gould (213-795-6811 X1828)

Investigator	Title
T. C. McGill	Electronic Properties of Semiconductor-Semiconductor Interfaces
J. O. McCaldin	Growth of Heterostructures by Novel Methods Including Characterization of Interfaces Produced
M. A. Nicolet	Analysis of Surface Layers Exposed to Ion Implantation

Columbia University: G. W. Flynn (212-280-4162)

Investigator	Title
W. Happer	Studies of Electronic and Nuclear Spin Polarization and Relaxation by Laser Optical Pumping of Gases
G. Flynn W. Happer	Two Photon Optical Pumping for Remote Sensing of Magnetic Fields
W. Happer	Relaxation Mechanisms for Highly Excited Alkali Atom-Noble-Gas Excimers
G. W. Flynn	Laser Studies of Intermode Energy Transfer Events in Small Molecules
G. W. Flynn	Metastable Collision Induced Vibrational Energy Storage and Population Inversion in Laser Pumped Polyatomic Molecules
G. W. Flynn	Vibration to Electronic and Electronic to Vibrational Energy Transfer in Laser Pumped Gases
G. W. Flynn	Energy Transfer and Energy Redistribution in Ultraviolet Laser Induced Photofragmentation Processes
K. Eisenthal	Picosecond Laser Studies of Vibrational Energy Relaxation in Molecules
K. Eisenthal	Picosecond Laser Studies of Photo-Induced Dissociation Dynamics and the Vibrational Relaxation of the Photofragments
S. R. Hartmann	Spontaneous and Induced Coherent Radiation, Generation and Control in Atomic Vapors
S. R. Hartmann	Relaxation and Excitation Transfer of Optically Excited States in Solids
M. C. Teich	Coherent Detection and Sensing in the Infrared
M. C. Teich	The Effects of Wave Noise on the Absorption and Detection of Infrared and Optical Radiation
M. C. Teich	Photon Count Antibunching for Optical Communications, Radar, Imaging, and Spectroscopic Applications
H. C. Card	Tunneling Spectroscopy of Si-SiO_2 Interface States Using Ultrathin SiO_2 Films
H. C. Card E. S. Yang	Carrier Transport Across Semiconductor Heterojunction Interfaces
H. C. Card M. C. Teich E. S. Yang	Electronic and Optoelectronic Processes in Metal-Germanium Schottky Barriers

Cornell University: L. F. Eastman (607-256-4369)

Investigator	Title
L. F. Eastman	Control of Compound Semiconductor Growth for Microwave Devices
J. Frey	Materials and Processes for Microwave Field Effect Devices
L. F. Eastman	Microwave Field Effect Transistor Performance Limits
L. F. Eastman	M.B.E. GaAs Microwave Power FET's
L. F. Eastman	Electric Current Controlled LPE of Compound Semiconductors
W. H. Ku	Advanced Design Techniques for Microwave GaAs FET Amplifiers
H. J. Carlin	Circuit Techniques for Active and Passive Distributed Parameter Systems
W. H. Ku	Optimum Design Techniques for Broadband Low-Noise FET Amplifiers

Georgia Tech: D. T. Paris (404-894-2902)

Investigator	Title
R. M. Mersereau R. W. Schafer	Two Dimensional Digital Signal Processing
E. W. Kamen	Theory of Two-Dimensional Systems
A. M. Bush	Nonlinear Systems and Multidimensional Digital Signal Processing
T. K. Gaylord	Optical Signal Processing
W. T. Rhodes	Hybrid Optical/Digital 2-D Signal Processing
T. P. Barnwell, III	Computers and Digital Systems

Harvard University: N. Bloembergen (617-495-3336)

Investigator	Title
H. Ehrenreich	Electronic Theory of Disordered Systems
M. Tinkham	Interaction of Laser Radiation and Superconductors
W. Paul	Structure, Optical and Transport Properties of Amorphous Semiconductors

Investigator	Title
P. S. Pershan	Liquid Crystals
N. Bloembergen	Nonlinear Spectroscopy
N. Bloembergen	Picosecond Nonlinear Optics
E. Yablonovitch	CO_2 Laser Radiation Interactions
R. W. Brockett	Stochastic and Deterministic Modeling with Applications to Control
Y. C. Ho	Research in Decision and Control
P. E. Caines	Information and Control
T. T. Wu	Electromagnetic Phenomena

University of Illinois: R. T. Chien (217-333-2510)

Investigator	Title
A. Y. Cho	Molecular Beam Epitaxy
G. E. Stillman	Characterization of High-Purity InP Grown by the PH_3-InP-Ga-HCL Technique
B. G. Streetman	Studies of Deep Level Impurities and Defects in Semiconductors
B. G. Streetman	Ion Implantation Doping of Semiconductors
J. E. Green	Semiconductor Crystal Growth by Ion Beam Sputtering: Ion-Surface Interactions
B. J. Hunsinger	Microwave Acoustic Charge Transport in Semiconductors
G. Ehrlich	Direct Examination of the Metal-Semiconductor Interface
G. Ehrlich	Chemical Processes on Semiconductor Surfaces
P. D. Coleman	Study of the Hot-Bands and Quasi-Continua of Gaseous Molecules
T. A. DeTemple	Energy Transfer Processes in Excited Atoms
J. T. Verdeyen	Excitation Transfer Between Excited States in Gas Discharges
R. Mittra	Electromagnetic Radiation and Scattering
R. Mittra	Millimeter Wave Integrated Circuits
J. B. Cruz	Control and Decision Strategies for Systems Under Imperfect Information

University of Illinois: R. T. Chien (217-333-2510)

Investigator	Title
J. B. Cruz	Implementation Constrained Decomposition and Hierarchical Control
D. P. Bertsekas	Computational Methods for Nonlinear Programming and Optimal Control
M. B. Pursley	Random-Access Schemes for Communication Satellites and Radio Networks
M. B. Pursley	Variable-Rate Universal Data Compression Theory and Techniques
M. B. Pursley	Spread-Spectrum, Multiple Access Communication Via Fading Channels
A. H. Haddad	Robust Digital Detection and Estimation
W. Mayeda	Macromodeling and Integrated Design of Large Scale Circuits and Systems
T. N. Trick	Fault Analysis of Analog Circuits
F. P. Preparata	Efficient Computation Techniques
E. S. Davidson	Computer Architecture
E. S. Davidson	Computer System Organization
E. S. Davidson	Modelling and Evaluation of Large Computer Systems
G. Metze	Concurrent Self-Diagnosis and Reconfiguration in Large Scale Digital Systems
J. Abraham	Fault-Tolerant Distributed Systems

MIT/RLE: P. A. Wolff (617-495-4595)

Investigator	Title
H. A. Haus	Picosecond Pulses from Semiconductor Lasers
J. Litster	Time-Resolved Spectroscopy of Condensed Matter
M. M. Salour	Picosecond Dye Laser Optics
S. Ezekiel	Use of Stabolized Lasers to Study Interaction of Radiation with Matter
D. E. Pritchard	Efficient Energy Transfer Processes in Atomic Collisions

Investigator	Title
D. Kleppner	Resonance Studies with Highly Excited Atoms
H. A. Hans	Frequency Stable Low-Threshold Injection Lasers
S. Ezekiel	Passive Ring Resonator Optical Gyroscope
M. S. Gupta	Noise in Semiconductor Microwave Devices
F. R. Morgenthaler	Magnetic Racetrack Resonator
F. R. Morgenthaler	Microwave Devices Employing Controlled Focusing of Magnetostactic Waves
R. J. Birgeneau	High Resolution X-Ray Scattering Spectroscopy of Condensed Matter
J. D. Joannopolos	Electronic Structure of Homopolar and Heteropolar Surfaces
R. McFeely	Electronic and Magnetic Structure of Solid Surfaces Using Photoelectron Spectroscopy
J. W. Coleman	Ultrahigh-Sensitivity Electron Optical Determination and Location of Impurity Species, etc.
M. Kastner	Electronic Properties of Charged Centers in SiO_2 - Like Glasses
R. H. Staley	Surface Synthesis by Gas Phase Ion Reaction
J. A. Kong	Electromagnetic Waves
D. H. Stallin	Actively Controlled Large Antennas
H. I. Smith	Submicron Device Fabrication

Ohio State University: C. H. Walter (614-422-6194)

Investigator	Title
R. G. Kouyoumjian P. H. Pathak N. N. Wang	Diffraction Studies
W. D. Burnside G. A. Thiele	Hybrid Techniques
E. H. Newman R. J. Garbacz	Antenna Studies
D. Moffatt E. M. Kennaugh	Time Domain Studies

Investigator	Title
R. T. Compton	Adaptive Array Studies
J. G. Meadors W. H. Peake J. D. Young	Laser Induced Microwave Radiation Study

Polytechnic Institute of New York: A. A. Oliner (212-643-2111)

Investigator	Title
S. T. Peng A. Hessel A. A. Oliner	Millimeter Wave Waveguides and Antenna Arrays
L. B. Felsen	Hybrid Ray-Mode Formulation of Ducted Propagation
F. Barone S. Gross N. Marcuvitz	Wave-Matter Interactions
T. Tamir A. A. Oliner L. B. Felsen	Optical Waveguiding Structures
B. Post H. J. Juretschke	X-Ray Guided Wave Electronics
B. Senitzky	Interaction of Millimeter Waves and Semiconductors
W. C. Wang H. Schachter	Acoustoelectric and Acousto-optic Devices
H. J. Juretschke	Electric and Magnetic Interactions in Thin Films and Surface Regions of Solids
E. Banks	New Solid State Materials
D. C. Mattis	Electronic Properties of Hydrogen in Solids
D. C. Youla F. Kozin J. J. Bongiorno, Jr.	Reduced Order Models of Large Scale Systems
A. Papoulis L. Kurz	Enhancement, Extraction and Reconstruction Techniques in Image Processing
L. Kurz	Robust Procedures in Estimation and Detection Procedures

University of Southern California: Z. A. Kaprelian (213-746-2481)

Investigator	Title
W. G. Spitzer C. N. Waddell	Optical Properties and Thermal Laser Annealing of Ion Implanted Semiconductors
K. Lakin	Thin Film Crystal Filters
A. Tanguay	Electrooptic Materials and Optical Image Storage Devices
C. Crowell	Electrical Techniques for Materials Characterization
M. Gershenzon	A GaP on Si Integrated Optics Chip
G. Narayanan	A Transmission Electron Microscopy Study of Radiation Damage Induced by Ion-Implantation in GaAs Single Crystals
C. P. Christensen W. Steier	Laser Devices and Applications
C. Wittig	Dynamic Processes in Chemically Pumped Lasers
J. J. Song	Frequency Dispersion of Third-Order Nonlinear Optical Susceptibility
A. A. E. Gamal	Multiple User Information Theory
L. Flon	Furthering Data Abstraction Verification
D. McLeod	User-Oriented Database Structure and Access
J. Hayes	Design of Easily Maintainable Systems
L. Silverman S. Y. Kung	Identification and Model Reduction Via Singular Value Decomposition Analysis on Hankel Matrix
M. Safanov	Multivariable Feedback System Design
A. Sawchuk T. Strand	Polychromatic Optical Information Processing
D. Russell	Checkpoint Recovery in Computer Systems

Stanford Electronics Labs: J. D. Meindl (415-497-1013)

Investigator	Title
M. Morf	Realtime Statistical Data Processing Algorithms
T. Kailath	Fast Estimation Algorithms and Some Problems in Theoretical Physics
A. T. Waterman, Jr.	Improved Resolution in Microwave Propagation Measurements

Investigator	Title
S. S. Owicki	Reliability in Distributed Database Systems
W. M. vanCleemput	Computer-Aided Layout of Very Large Scale Integrated Circuits
M. E. Hellman	Signal Processing and Compression
J. D. Meindl	Very Large Scale Integration
F. W. Crawford	Generation of Intense Microwave Radiation

Stanford Ginzton Lab: M. Chodorow (415-497-0201)

Investigator	Title
M. R. Beasley	Superconducting Electronics with High T_c Materials
G. S. Kino	Acoustic Surface Wave Scanning of Surface Optical Images
H. J. Shaw	Nonlinear Fiber Optic Interactions with Application to High Speed Signal Processing
B. A. Auld	Nonlinear Interactions of Acoustic Waves with Domains in Ferroic Materials
A. E. Siegman	Measurement of Ultrafast Physical Phenomena
S. E. Harris	A VUV and Soft X-Ray Light Source

University of Texas at Austin: E. J. Powers (512-471-3954)

Investigator	Title
S. I. Marcus T. J. Wagner G. L. Wise	Nonlinear Filtering and Estimation
J. K. Aggarwal	Electronic Multi-Dimensional Signal Processing
S. A. Szygenda E. W. Thompson T. K. M. Agerwala G. J. Lipouski	Electronic Computer Design and Analysis
R. T. Yeh	Electronic Computer Software Systems
R. W. Bene' R. M. Walser A. B. Buckman	Basic Solid State Materials Research

Investigator	Title
R. M. Walser R. W. Bene' M. F. Becker J. P. Stark J. S. Turner	Research on Instabilities and Transport Near Surfaces and Interfaces of Solids
M. F. Becker E. J. Powers	Nonlinear Wave Phenomena
L. Frommhold M. Fink	Atomic and Molecular Atomic Processes
J. Keto M. F. Becker	High Power Laser Systems

Texas Tech University: R. Saeks (806-742-3528)

Investigator	Title
R. Saeks	Nonlinear Fault Analysis
K. S. Chao	Qualitative Analysis of Large Scale Systems
J. Murray	Multidimensional System Theory
J. F. Walkup	Optical Noise
T. Newman	Pattern Recognition
R. Saeks	Quadratic Optimization Problems
L. R. Hunt	Nonlinear Control
J. F. Walkup	Real Time Optical Signal Processing

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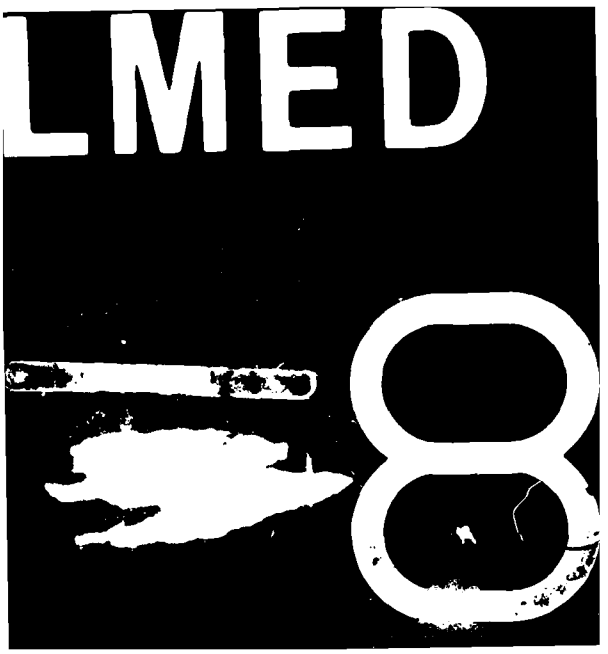
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